INSTRUMENTATION APPENDIX TO PERIODIC INSPECTION REPORT NO. 5 KNIGHTVILLE DAM, MASSACHUSETTS

by

Haley & Aldrich, Inc.
Cambridge, Massachusetts

for

Department of the Army
New England Division

File No. 11163-006
July 1995

INSTRUMENTATION APPENDIX

TO PERIODIC INSPECTION REPORT NO. 5

KNIGHTVILLE DAM, MASSACHUSETTS

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

LIST OF APPENDICES

1. Project Performance

Based on visual observation and instrumentation data compiled to date, the performance of Knightville Dam is rated as good. An initial crest monument survey was performed by Corps of Engineers, New England Division Surveyors in June 1985. A second crest monument survey was performed in February 1991. Strong motion accelerographs are functioning as designed.

Seven of the eleven original piezometers were abandoned in 1989. Five double piezometers were added to replace the original piezometers. There are currently four single piezometers and five double piezometers at the dam. The new double piezometers and two of the original piezometers are functioning as designed. Two of the original piezometers, PZ-4 and PZ-11, appear to be malfunctioning. This conclusion is based on the observed water level readings and the results of falling head permeability tests.

Piezometric water levels at Knightville Dam are generally higher than pool level and appear to be governed by seepage from the abutments and the base of the dam. Upstream piezometric levels are generally higher than downstream levels, indicating that the dam is functioning as designed.

2. General Project Description

a. History. Knightville Dam is part of a system of 16 dams and reservoirs that has been constructed in the Connecticut River Basin for flood control purposes. Knightville Dam, Littleville Lake and the West Springfield Local Protection Project have been constructed to provide flood protection for the Westfield River Basin and to control flood flows on the Connecticut River.

Authorization for Knightville Dam is contained in the Flood Control Act approved 22 June 1936, Public Law No. 738, 74th Congress and amended by Public Law No. 111, 75th Congress and approved 25th May 1937. A survey report dated 20 March 1937 reviewing previous reports on flood control for the Connecticut River Basin was authorized by Public Law No. 761, 75th Congress and approved 28 June 1938. The report was printed as House Document 445, 75th Congress, 2nd Session. The project was started in August 1939 and completed in December 1941.

Knightville Dam is located in west-central Massachusetts on the main branch of the Westfield River, four miles north of the town of Huntington, Massachusetts, about 12 miles west of the City of Northampton, Massachusetts, and about 27.5 miles north of the confluence of the Westfield River with the Connecticut River in West Springfield, Massachusetts. The project locus is shown in Figure 1.

b. Geology and Foundations

(1) General. The watershed of the Westfield River for the Knightville Dam is located on the west side of the Connecticut River valley. A large part of the drainage area is in the rugged

upland region composed of geologic formations which are strikingly different from those underlying the extensive Connecticut River lowland. The geologic formations of the highlands are made up of ancient crystalline rock of igneous and metamorphic origin. The geologic formations of the lowlands are much younger and composed chiefly of slightly inclined sedimentary strata. These softer formations are in turn overlain by thick glacial deposits.

Throughout this area, the Westfield River flows through a broad and relatively shallow valley. From its headwaters to about 12 miles west of its confluence with the Connecticut River, where highland and lowland areas are contiguous, the river flows through a narrow and steep-sided valley.

(2) Site Geology. At the dam site shown in Figure 2, the river flows through a gorge-like area, located on the west side of the large and deeply buried pre-glacial valley. Rock is intermittently exposed on the right bank from below the river level to well above the top of the dam. On the left bank, within a narrow area extending from the centerline of the dam to about 600 ft. downstream, the rock surface rises precipitously from below river level to a maximum height of about 60 ft. above the stream. Bedrock on the left bank is actually on the west side of the pre-glacial valley since the rock surface dips beneath glacial overburden toward the much older channel. The maximum thickness of overburden, approximately 160 ft., occurs beneath the extreme left abutment. The formation predominantly consists of an unstratified and dense glacial till. The area on the right bank, partly enclosed by a bend in the river, contains frequent rock exposures. Outcrops occur in the river for several hundred feet below the centerline of the dam. Quartzitic and micaceous schist is prominently developed throughout the area with igneous rocks, chiefly coarse granite or pegmatite forming intrusive dikes and veins.

The outlet tunnel is excavated in steeply inclined beds of quartzitic and micaceous schist. These rocks are a part of extensive metamorphic formations, occurring throughout western Massachusetts, composed originally of fine-grained sediments, chiefly sand and silt. Orientation of the tunnel is nearly parallel to the bedding structure of the schist.

The spillway weir and retaining wall are founded upon bedrock similar to that in the outlet works. Excavation for the foundation was carried through the shallow overburden and into the bedrock. The average depth to suitable rock was about 4 ft., except in localized areas where weathering of the more micaceous schist was deeper.

c. Dam and Appurtenant Structures Description. Typical as-built profiles and cross sections of the dam are shown in Figures 3 and 4. The dam embankment is an earth fill with a maximum height of 160 ft. and a crest at El. 630. Upstream and downstream slopes are 2.5H:1V (horizontal:vertical) above El. 610 and 3H:1V below El. 610. The embankment was placed by the hydraulic fill method to El. 605, while the remainder of the embankment and the upstream cofferdam was built as a rolled fill. The central portion of the embankment consists of a selected impervious fill. The outer sections consist of a pervious material, graded from finer sizes near the impervious section to coarser sizes near the outer slopes. The upstream and downstream face of the embankment are protected with dumped rock, with rock toes at the foot of each slope. A cut-off trench was excavated in the left abutment to a depth varying from 5 to 15 ft. In the right abutment where overburden was excavated to bedrock in the core area, a grout curtain was constructed in the bedrock foundation. A 70-ft. high concrete retaining wall was constructed across the river at the downstream toe of the dam in order to protect the embankment from erosion by the outlet flow.

The outlet works, which is located on the right abutment of the dam, consists of an intake channel, an intake structure with a transition section located in the intake tower, a tunnel section and an outlet portal. All outlet works structures are founded on rock. The intake channel is 30 ft. wide and 250 ft. long. The channel is excavated in rock with side slopes of 4H:1V (horizontal:vertical) and has a bottom at El. 480. The intake tower is located on the upstream slope of the dam over the outlet works. Flow through the outlet works is controlled by three 6 ft. wide by 12 ft. high service gates. The tower is founded on rock and is reached from the end of the dam by a three-span service bridge.

The spillway weir is a 400 ft. long overflow ogee gravity section that is convex upstream and has a crest at El. 610. The weir is constructed on solid rock and contains a grout curtain. A retaining wall was constructed on the right (east) side of the spillway to separate the earth fill embankment from the spillway weir. The concrete downstream toe wall, located across the original river channel, has three 4 ft. wide by 3 ft. high weep holes to drain the interior rock fill section just upstream of the wall. The weep holes have inverts at El. 472, two feet above normal tailwater at El. 470.

Knightville Dam holds a winter pool at about El. 500 from about 1 December to 1 April according to the Instrumentation Appendix published in 1989. During the remainder of the year, no pool is maintained and the upstream water levels are at the intake channel, about El. 480.

3. Instrumentation

a. Crest Monuments. Seven crest survey monuments and four control points were installed at the dam in November 1984 as shown on Figure 5. No initial elevations or horizontal coordinates were established on the monuments at the time of installation. A survey was performed in June 1985 by Corps of Engineers, New England Division Surveyors. The composition of the crest monuments, labeled Mon-1 through Mon-7 is partially known. The assumed depth is 5 ft. of 4-in. PVC pipe filled with concrete and reinforcing rods. A brass disk is set in the top of each monument. Four control points were installed at the dam labeled "A" through "D" on Figure 5. Control Points "A," "B" and "C" are used for horizontal control and Control Point "D" is used as a benchmark for vertical control. The Corps of Engineers survey was performed using Electronic Distance Meter (EDM) instruments. The current standards and procedures employed by Corps of Engineers Surveyors for crest monument surveys at Knightville Dam are contained in Appendix A.

b. Piezometers. During construction of the dam, eleven elevation settlement gauges were installed at Knightville Dam. Seven of the eleven settlement gauges were abandoned as discussed below. The remaining four settlement gauges, hereinafter referred to as piezometers based on their actual use, were installed at the locations shown on Figure 5. Piezometers consist of a steel plate set at about the interface of the embankment and the foundation with a 4-in. steel riser pipe extending through the outer slope of the embankment. The lower portion of the pipe is perforated and surrounded by a pervious filter so that internal pore water pressure may be measured. Design bottom elevations for the piezometers installed during construction of the dam are taken from construction data. Actual bottom elevations are calculated from an August 1988 survey of riser top elevations and soundings taken on 26 May 1988. All elevations are in feet and refer to the National Geodetic Vertical Datum (NGVD) of 1929.

Based on the recommendations in the March 1989 Instrumentation Appendix, seven of the old piezometers were abandoned. PZ-1 and PZ-10 were consistently dry. PZ-2 and PZ-3 could not be read with the water level indicators used by New England Division due to the poor condition of the small diameter inner riser pipes. PZ-5 was located on the upstream slope 307 ft. from the centerline of the dam and was inundated by the reservoir once the pool reached the 50-ft. stage, El. 530. PZ-13A and PZ-13B were installed to replace PZ-6 and PZ-7. Abandoned piezometers were filled with a cement/bentonite grout and the riser pipes cut off a minimum of 1 ft. below the riprap surface.

Additional piezometers were installed at Knightville Dam in 1989 to better determine the effectiveness of the impervious core, foundation cutoff and grout curtain and to determine the piezometric level within these zones. Five double piezometers (PZ-12A, PZ-12B; PZ-13A, PZ-13B; PZ-14A, PZ-14B; PZ-15A, PZ-15B; PZ-16A, PZ-16B) were installed at the locations shown on Figure 5. Installation data for these piezometers including the general legend and the engineering logs are shown on Figures 6 and 7. When plotted against the typical embankment profile and cross sections, the engineering logs provide confirmation of the general site geology and dam construction as discussed previously. Refer to Figures 8 through 11 for the typical profile and cross sections.

Riser elevations were determined by survey after the instruments were installed. The installation of these piezometers permits an evaluation of the seepage control of the embankment and cutoff and a determination of piezometric levels within the foundation of the dam. The new piezometers were constructed with filter fabric sand zones around a 1.5-in. by 24-in. pervious plastic piezometer tip and bentonite seals as shown on Figure 7.

c. Strong Motion Accelerographs. Three strong motion accelerographs (Shelters A, B and C) were installed at Knightville Dam in 1976 to monitor shock wave attenuation through the embankment and foundation during an earthquake. All strong motion accelerographs at Knightville Dam are SMA-1 accelerographs housed in concrete shelters. Shelter "B" is located at the downstream crest of the embankment just outside the guardrail at Station 8+10. Shelter "A," founded on bedrock, and Shelter "C," founded on glacial till, are located downstream of the embankment about 215 ft. and 590 ft. below the downstream toe, respectively. The location of the shelters is shown in Figure 5. The SMA-1 accelerograph is a compact, portable, self-contained unit with an accelerometer for measuring accelerations in three orthogonal directions. The units are activated automatically by a trigger sensitive to vertical accelerations of 0.01g.

4. Data Collection, Interpretation and Evaluation

a. Crest Monuments

(1) Data Collection. The coordinates and elevations of the crest monuments which were determined from surveys conducted in June 1985 and February 1991 are shown in Figure 12 along with dimensions between control points and crest monuments for the February 1991 survey. Computed horizontal and vertical movements of each monument are plotted on Figure 13.

The surveys were performed by recording angles and distances from Control Points "A," "B," and "C" to the crest monuments and the coordinates were calculated by a combination of trilateration and triangulation as outlined in Appendix A. Elevations of the crest monuments were established using Control Point "D" as a benchmark (El. 631.053).

(2) Interpretation and Evaluation. Two surveys were performed using an electronic distance meter (EDM) with third order accuracy (1:5000) according to the standards and procedures contained in Appendix A.

The survey results indicate that the total rise or settlement of all monuments was limited to, or less than, 0.04 ft. over the six-year period. This range of movement is within the range of third order accuracy. Note that Mon 1 apparently heaved about 0.01 ft. This apparent heave probably relates to survey error. Thus allowing for some survey error, minor settlement of the embankment on the order of 0.03 to 0.05 ft. seems likely. This small amount of settlement or rise is considered tolerable.

The computed horizontal movements are less than 0.12 ft. between 1985 and 1991. This range of movement is within the range of third order accuracy so it is possible that no movement occurred at all. Based on the variable direction of displacement shown in Figure 13, no pattern of displacement was discerned. However, minor movement of the embankment could have occurred. This small amount of movement is considered negligible.

b. Piezometers

(1) Data Collection. Settlement readings and water level readings were taken at the settlement gauges/piezometers for the first 33 months after the start of construction and were reported in the March 1989 Instrumentation Appendix. After that period, no settlement measurements were obtained from the settlement gauges/piezometers. Water levels were recorded during the April 1987 flood event and were published in the March 1989 Instrumentation Appendix. Periodic measurements have been made since March 1990. The proposed schedule was not followed between March 1990 and November 1994 due to staff shortages and limited access in the winter. A more complete evaluation of piezometer typical response could be made if data were collected according to schedule.

(a) Schedule. The schedule for reading all piezometers at Knightville Dam is as outlined below. Pool elevations, tailwater elevations, weir discharge quantities and rainfall data should be recorded when readings are taken and all data should be sent to Geotechnical Engineering Division (GED). In addition to the reading schedule below, all piezometers should be sounded to the bottom once per year and the results sent to GED.

(1) Routine. During periods when the pool is below the 40.0 ft. stage, El. 520.0, readings of all piezometers should be made once per month. When access to instruments is made hazardous by snow or ice, the readings may be deferred until safe access is possible.

(2) High Pool. During periods when the reservoir pool is above the 40.0 ft. stage, El. 520.0, including rising and falling pools, readings should be made on a daily basis. On a falling pool, the piezometers should continue to be read on a daily basis for five days after the pool has returned to its normal elevation.

(3) Special Conditions. If unusual changes in readings develop or if piezometers become inoperable, GEB should be contacted and made aware of the problem.

(2) Interpretation and Evaluation. Knightville Dam holds a winter pool at about El. 500, pool stage 20 ft., from about 1 December to 1 April. During the remainder of the year, no pool is maintained with upstream water levels at the intake channel, El. 480. Due to the narrow intake channel, the pool stage rises rapidly to approximately El. 523 during a rising pool.

During both the summer and winter months, the "average" water level in each piezometer was calculated using water levels obtained when the pool was close to its normal level. For example, for a normal winter pool level at El. 500, piezometric water levels were used to calculate the average water level if the pool fell between El. 498 and El. 502. However, because of staff shortages and limited access to the piezometers during winter months, there are limited data available. Therefore, any water levels measured when the pool fell between El. 498 and El. 502 were used to calculate the average level regardless of time of year. This same procedure was used to calculate average water levels during summer pool (e.g. any data obtained when the pool was between El. 478 and El. 482 was used). It should be noted that these "average" piezometric water levels were calculated based on a very limited set of data and may not be representative of the actual average levels. However, in order to create a basis for comparison to the high pool data, these "average" levels were calculated.

(a) Presentation of Data. Numerous plots were developed to present the piezometric data. All plots were developed using "Quattro Pro for Windows" Version 6.0 computer software. The piezometer plots fall into three categories: time-history, event and "x-y" plots.

Time-history plots were developed for years 1990-1994 and are presented on Figures 14 through 20. Event plots were produced for the March 1990 flood event and are shown on Figures 21 through 27. An x-y plot of piezometer water level elevation vs. pool elevation was developed for each piezometer and is shown on Figures 28 through 41. These plots incorporate piezometric data from 19 March 1990 through 23 November 1994. Also plotted is a projection of the piezometer level corresponding to a pool elevation at the spillway crest. This projection was calculated by linearly regressing the piezometer data and plotting the regression line.

(b) Individual Piezometer Response. All pertinent information (station, offset, tip elevations, zone and material type at tip location) for each piezometer is included in Table I. The piezometer data is included in Tables II and III. The following paragraphs summarize the performance of each piezometer during normal steady state operation and the response to the March 1990 flood event.

(1) PZ-4 PZ-4 is located at Sta. 6+00 and is offset 190 ft. upstream from the dam centerline. PZ-4 was installed as a settlement plate during construction of the dam. PZ-4 is not shown on the engineering log profile and sections because an engineering log is not available for this piezometer. The top of the riser pipe is at El. 569.3. The piezometer tip is located at El. 531.0. Based on drawings published in the 1989 Instrumentation Appendix, the material influencing the piezometer tip is apparently a gravelly SAND and sandy GRAVEL.

Figure 16 shows PZ-4 water levels between March 1990 and November 1994. The normal average water level in PZ-4 during the winter months is about El. 554 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 54 ft. higher than normal pool and appears to be attributable to piezometer malfunction, as discussed below. The normal piezometric level during the summer months is about El. 539 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 39 ft. higher than normal pool which probably may be attributed to piezometer malfunction, as discussed below.

Because PZ-4 generally had either very high water levels or was dry, a falling head permeability test was performed to evaluate piezometer response. On Friday, 9 June 1995, a site visit was conducted by H&A and GED personnel. A falling head test was performed on PZ-4 by adding approximately 10 gallons of water to the riser pipe. Essentially no change in water level was observed during the first 34 minutes of the test. Therefore, no further readings were taken until the following Monday, 12 June 1995. On Monday, the water level had dropped about 3 ft. The results of the permeability test indicate that the piezometer tip is probably plugged, with a permeability on the order of 10^{-7} cm/s.

Although PZ-4 appears to be plugged, the piezometer did show response to the high pool in March 1990. Based on the March 1990 flood event shown in Figure 23, the following performance was noted. The water level in PZ-4 rose from its average level about 10 ft. to El. 564.6 compared to a pool increase of 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-4 water levels fell from a high level on 22 March to lower levels through 29 March. No data is available before 22 March for PZ-4; therefore, the high water level on 22 March may not represent a peak level. However, after the peak pool level, the pool and piezometer levels dropped at the similar times, indicating that the piezometer response time was about one day or less. However, PZ-4 water levels dropped at a very slow rate relative to the rate of decrease of the pool level, probably due to the plugged piezometer tip.

The measured water levels in PZ-4 generally increase with increasing pool level as shown in Figure 28. Based on the linear projection, PZ-4 should rise to El. 571.7 when the pool rises to the spillway crest at El. 610. However, this projected level is above the riser elevation and the piezometer would be overtopped before the pool reached the spillway crest.

(2) PZ-8 PZ-8 is located at Sta. 8+75 and is offset 90 ft. downstream from the dam centerline. PZ-8 was installed as a settlement plate during construction of the dam. PZ-8 is not shown on the engineering profile and sections because an engineering log is not available for this piezometer. The top of the riser pipe is at El. 604.7. The piezometer tip is located in the foundation at El. 473.6. Based on drawings published in the 1989 Instrumentation Appendix, the material influencing the piezometer tip is apparently a gravelly SAND and sandy GRAVEL.

The normal average water level in PZ-8 during the winter months is about El. 496 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is slightly below the normal pool level, as would be expected for a piezometer downstream of the impervious core. Any excess head due to artesian seepage from the foundation is not evident during winter months. The normal average water level during the summer months is about El. 493 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 13 ft. above normal pool and could be attributed to seepage from the foundation which is evident in summer months. In winter months, artesian seepage from the foundation is not evident because pool levels are higher, thus increasing piezometric levels above "background" levels due to seepage. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 17. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 24.

Based on the March 1990 flood event shown in Figure 24, the following performance was noted. The water level in PZ-8 rose from its average level about 4 ft. to El. 500.0 compared to a pool increase of about 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-8 water levels rose to a peak level on 27 March and fell to lower levels through 29 March. The peak water level at PZ-8 apparently occurred on 27 March indicating a response time of about six days.

The measured water levels in PZ-8 appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 29. However, the change in piezometric level is small relative to the change in pool level. Based on the linear projection, PZ-8 should rise to only El. 499.0 when the pool rises to the spillway crest at El. 610.

(3) PZ-9 PZ-9 is located at Sta. 8+75 and is offset 190 ft. downstream from the dam centerline. PZ-9 was installed as a settlement plate during construction of the dam. PZ-9 is not shown on the engineering profile and sections because an engineering log is not available for this piezometer. The top of the riser pipe is at El. 568.8. The riser pipe is blocked at El. 475.4; therefore, the elevation of the piezometer tip is not known. It is believed that the piezometer tip is located in the foundation of the dam. Based on drawings published in the 1989 Instrumentation Appendix, the material influencing the piezometer tip is apparently a gravelly SAND and sandy GRAVEL.

The normal average water level in PZ-9 during the winter months is about El. 487 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is below the normal pool level, as would be expected for a piezometer downstream of the impervious core. Any excess head due to artesian seepage from the foundation is not evident during the winter months. The normal average water level during the summer months is about El. 485 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 5 ft. above normal pool and could be attributed to seepage from the foundation which is evident in summer months. In winter months, seepage from the foundation is not evident because pool levels are higher, thus increasing piezometric levels above "background" levels due to seepage. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 17. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 24.

Based on the March 1990 flood event shown in Figure 24, the following performance was noted. The water level in PZ-9 rose from its average level about 2 ft. to El. 489.1 compared to a pool increase of about 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-9 water levels rose to a peak level on 27 March and fell to lower levels through 29 March. The peak water level at PZ-9 apparently occurred on 27 March, indicating a response time of about six days.

The measured water levels in PZ-9 appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 30. However, the change in piezometric level is small relative to the change in pool level. Based on the linear projection, PZ-9 should rise to only El. 490.5 when the pool rises to the spillway crest at El. 610.

(4) PZ-11 PZ-11 is located at Sta. 11+00 and is offset 90 ft. upstream from the dam centerline. PZ-11 was installed as a settlement plate during construction of the dam. PZ-11 is not shown on the engineering profile and sections because an engineering log is not available for this piezometer. The top of the riser pipe is at El. 603.2. The piezometer tip is located in the shoulder fill at El. 549.2. Based on drawings published in the 1989 Instrumentation Appendix, the material influencing the piezometer tip is apparently a gravelly SAND and sandy GRAVEL.

The normal average water level in PZ-11 during the winter months is about El. 568 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 68 ft. higher than normal pool which could be attributed to piezometer malfunction, as discussed below. PZ-11 was dry during the summer months as noted in Table II for normal river levels ranging from El. 478 to 482. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. In addition, most of the irregular monthly readings were recorded as "dry" and consequently there is very limited data available for PZ-11.

Because PZ-11 was usually dry and occasionally had very high water levels, a falling head permeability test was performed to evaluate piezometer response. On Friday, 9 June 1995, a site visit was conducted by H&A and GED personnel. A falling head test was performed on PZ-11 by adding approximately 10 gallons of water to the riser pipe. Essentially no change in water level was observed during the first 20 minutes of the test. Therefore, no further readings were taken until the following Monday, 12 June 1995. On Monday, the piezometer was dry. Although the rate of head loss is unknown, the initial data suggests a very slow rate of head loss. The permeability at the piezometer tip is probably on the order of 10^{-6} cm/s, assuming the piezometer dried up on Monday morning. The piezometer tip appears to be plugged, since 10^{-6} cm/s is not a typical permeability value for gravelly SAND and sandy GRAVEL.

During the flood event of March 1990, PZ-11 was dry; therefore, the response time of the piezometer could not be evaluated. The measured water levels in PZ-11 appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 31. However, the linear projection indicates that water levels in PZ-11 decrease with increasing pool elevation. This discrepancy may be attributed to the small amount of data on which the regression was performed. For example, if one questionable data point, "A" as shown on Figure 31, were removed, the piezometer would show little response to changes in pool level.

(5) PZ-12A PZ-12A is located at Sta. 6+00 and is offset 10 ft. downstream from the dam centerline as shown in Figure 9. The top of the riser pipe is at El. 630.3. The piezometer tip is located near the foundation interface at El. 521.3. PZ-12A was installed in 1989 with a wick of filter sand which extends upward 9 ft. from El. 521.3 to a bentonite seal. The material influencing the piezometer tip is a medium brown SILT with sand (22).

The normal average water level in PZ-12A during the winter months is about El. 530 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 30 ft. higher than normal pool which could be attributed to seepage from the foundation of the dam. The normal average water level during the summer months is about El. 529 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 49 ft. higher than normal pool which could be attributed to artesian seepage from the foundation of the dam. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 14. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 21.

Based on the March 1990 flood event shown in Figure 21, the following performance was noted. Measurements for 22 and 23 March show an unusual drop in the piezometric level. These readings were not used in the following analysis. The water level in PZ-12A rose from its average level about 3 ft. to El. 533.0 compared to a pool increase of 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-12A water levels fell from a peak level on 24 March to lower levels through 29 March. The peak water level at PZ-12A apparently occurred on 24 March; therefore, it appears the response time is about three days.

The measured water levels in PZ-12A appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 32. Based on the linear projection, PZ-12A should rise about 3 ft. to El. 532.4 when the pool rises to the spillway crest at El. 610.

(6) PZ-12B PZ-12B is located at Sta. 6+00 and is offset 10 ft. downstream from the dam centerline as shown in Figure 9. The top of the riser pipe is at El. 630.3. The piezometer tip is located in the foundation soil at El. 509.3. PZ-12B was installed in 1989 with a wick of filter sand which extends upward 6 ft. from El. 509.3 to a bentonite seal. The material influencing the piezometer tip is a medium brown silty (30-40) SAND with gravel (5-15).

The normal average water level in PZ-12B during the winter months is about El. 530 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 30 ft. higher than normal pool which could be attributed to artesian seepage from the foundation of the dam. The normal average water level during the summer months is about El. 528 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 48 ft. higher than normal pool which could be attributed to seepage from the foundation of the dam. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 15. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 22.

Based on the March 1990 flood event shown in Figure 22, the following performance was noted. Measurements for 22 and 23 March show an unusual drop in the piezometric level. These readings were not used in the following analysis. The water level in PZ-12B rose from its average level about 4 ft. to El. 534.2 compared to a pool increase of 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-12B water levels fell from a peak level on 24 March to lower levels through 29 March. The peak water level at PZ-12B apparently occurred on 24 March; therefore, it appears the response time is about three days.

The measured water levels in PZ-12B appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 33. Based on the linear projection, PZ-12B should rise about 4 ft. to El. 534.3 when the pool rises to the spillway crest at El. 610.

(7) <u>PZ-13A</u> PZ-13A is located at Sta.7+90 and is offset 120 ft. upstream from the dam centerline as shown in Figure 10. The profile of PZ-13A has been projected to the cross section drawn at Sta. 8+75 as shown in Figure 10. The top of the riser pipe is at El. 598.5. The piezometer tip is located at El. 477.4 at the base of the shoulder fill. PZ-13A was installed in 1989 with a wick of filter sand which extends upward 102 ft. from El. 477.4 to a bentonite seal. The material influencing the piezometer tip is light brown silty (15-25) SAND with gravel.

The normal average water level in PZ-13A during the winter months is about El. 520 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 20 ft. higher than normal pool which could be attributed to artesian seepage from the foundation of the dam. The normal average water level during the summer months is about El. 502 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 22 ft. higher than normal pool which again could be attributed to artesian seepage from the foundation of the dam. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 18. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 25.

Based on the March 1990 flood event shown in Figure 25, the following performance was noted. The water level in PZ-13A rose from its average level about 43 ft. to El. 562.6 compared to a pool increase of about 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-13A water levels fell from a peak level on 22 March to lower levels through 29 March. The peak water level at PZ-13A apparently occurred on 22 March; therefore, it appears the response time is about one day.

The measured water levels in PZ-13A appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 34. Based on the linear projection, PZ-13A should rise to El. 592.0 when the pool rises to the spillway crest at El. 610. Note that the riser pipe will be overtopped as the pool rises to the spillway crest.

(8) PZ-13B PZ-13B is located at Sta. 7+90 and is offset 120 ft. upstream from the dam centerline as shown in Figure 10. The log of PZ-13B has been projected to the cross section drawn at Sta. 8+75 as shown in Figure 10. The top of the riser pipe is at El. 598.5. The piezometer tip is located in the foundation rock at El. 445.5. PZ-13B was installed in 1989 with a wick of filter sand which extends upward 25 ft. from El. 445.5 to a bentonite seal. The material influencing the piezometer tip is bedrock.

The normal average water level in PZ-13B during the winter months is about El. 515 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 15 ft. higher than normal pool which could be attributed to artesian pressure in the rock. The normal average water level during the summer months is about El. 504 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 24 ft. higher than normal pool which again could be attributed to artesian pressure from the bedrock foundation. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 19. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 26.

Based on the March 1990 flood event shown in Figure 26, the following performance was noted. The water level in PZ-13B rose from its average level about 28 ft. to El. 543.2 compared to a pool increase of about 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-13B water levels fell from a peak level on 21 March to lower levels through 29 March. The peak water level at PZ-13B apparently occurred on 21 March; therefore, it appears the response time was less than one day.

The measured water levels in PZ-13B appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 35. Based on the linear projection, PZ-13B should rise to El. 563.8 when the pool rises to the spillway crest at El. 610. Note that the riser pipe will be overtopped as the pool rises to the spillway.

(9) PZ-14A PZ-14A is located at Sta. 8+40 and is offset 10 ft. downstream from the dam centerline as shown in the cross section drawn at Sta. 8+75, as shown in Figure 10. The top of the riser pipe is at El. 629.9. The piezometer tip is located at El. 474.0 in the foundation soil at the base of the impervious core fill. PZ-14A was installed in 1989 with a wick of filter sand which extends upward 11 ft. from El. 474 to a bentonite seal. The material influencing the piezometer tip is a medium brown silty SAND and GRAVEL.

The normal average water level in PZ-14A during the winter months is about El. 503 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 3 ft. higher than normal pool which could be attributed to slight artesian seepage from the foundation of the dam. The normal average water level during the summer months is about El. 497 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 17 ft. higher than normal pool which could be attributed to artesian pressure from the foundation of the dam. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 14. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 21.

Based on the March 1990 flood event shown in Figure 21, the following performance was noted. The water level in PZ-14A rose from its average level about 10 ft. to El. 513.2 compared to a pool increase of 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-14A water levels fell from a peak level on 21 March to lower levels through 29 March. The peak water level at PZ-14A apparently occurred on 21 March; therefore, it appears the response time was less than one day.

The measured water levels in PZ-14A appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 36. Based on the linear projection, PZ-14A should rise to El. 525.4 when the pool rises to the spillway crest at El. 610.

(10) <u>PZ-14B</u> PZ-14B is located at Sta. 8+40 and is offset 10 ft. downstream from the dam centerline as shown in Figure 10. The top of the riser pipe is at El. 629.9. The piezometer tip is located in the foundation rock at El. 462.0. PZ-14B was installed in 1989 with a wick of filter sand which extends upward 2 ft. from El. 462.0 to a bentonite seal. The material influencing the piezometer tip is bedrock.

The normal average water level in PZ-14B during the winter months is about El. 503 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 3 ft. higher than normal pool which could be attributed to slight artesian pressure from the foundation of the dam. The normal average water level during the summer months is about El. 496 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 16 ft. higher than normal pool which could be attributed to artesian seepage from the foundation of the dam. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 15. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 22.

Based on the March 1990 flood event shown in Figure 22, the following performance was noted. The water level in PZ-14B rose from its average level about 12 ft. to El. 514.7 compared to a pool increase of 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-14B water levels fell from a peak level on 21 March to lower levels through 29 March. The peak water level at PZ-14B apparently occurred on 21 March; therefore, it appears the response time was less than one day.

The measured water levels in PZ-14B appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 37. Based on the linear projection, PZ-14B should rise to El. 528.7 when the pool rises to the spillway crest at El. 610.

(11) <u>PZ-15A</u> PZ-15A is located at Sta. 8+75 and is offset 135 ft. downstream from the dam centerline as shown in Figure 10. The top of the riser pipe is at El. 589.8. The piezometer tip is located at El. 478.9 in or very close to the pervious horizontal drainage layer at the base of the downstream slope. PZ-15A was installed in 1989 with a wick of filter sand which extends upward

88 ft. from El. 478.9 to a bentonite seal. The material influencing the piezometer tip is a medium brown silty (5-15) SAND.

The normal average water level in PZ-15A during the winter months is about El. 495 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is slightly below the normal pool level, as would be expected for a piezometer downstream of the impervious core. Any excess head due to seepage from the foundation is not evident during the winter months. The normal average water level during the summer months is about El. 491 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 11 ft. above normal pool and could be attributed to artesian seepage from the foundation which is evident in summer months. The piezometer was installed at the level of the horizontal pervious fill layer which undoubtedly serves as a drainage layer beneath the downstream slope and provides partial pressure relief for the artesian pressure, or any higher values of seepage induced pressure. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 18. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 25.

Based on the March 1990 flood event shown in Figure 25, the following performance was noted. The water level in PZ-15A rose from its average level about 3 ft. to El. 497.4 compared to a pool increase of about 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-15A water levels fell from a peak level on 25 March to lower levels through 29 March. The peak water level at PZ-15A apparently occurred on 25 March; therefore, it appears the response time was about four days.

The measured water levels in PZ-15A appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 38. Based on the linear projection, PZ-15A should rise to El. 501.7 when the pool rises to the spillway crest at El. 610.

(12) PZ-15B PZ-15B is located at Sta. 8+75 and is offset 135 ft. downstream from the dam centerline as shown in Figure 10. The top of the riser pipe is at El. 589.8. The piezometer tip is located in the foundation rock at El. 462.5, just below the pervious horizontal drainage layer. PZ-15B was installed in 1989 with a wick of filter sand which extends upward 10 ft. from El. 462.5 to a bentonite seal.

The normal average water level in PZ-15B during the winter months is about El. 492 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is slightly below the normal pool level, as would be expected for a piezometer downstream of the impervious core. Any excess head due to artesian seepage from the foundation is not evident during the winter months. The normal average water level during the summer months is about El. 490 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 10 ft. above normal pool and could be attributed to artesian seepage from the foundation which is evident in summer months. Fractures in the upper surface of bedrock probably provide a hydraulic connection between the piezometer wick and the horizontal drainage layer. Therefore, similar to PZ-15A, the drainage layer provides a partial pressure relief, reducing peak pressures recorded at PZ-15B.

Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 19. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 26.

Based on the March 1990 flood event shown in Figure 26, the following performance was noted. The water level in PZ-15B rose from its average level about 5 ft. to El. 497.2 compared to a pool increase of 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-15B water levels fell from a peak level on 25 March to lower levels through 29 March. The peak water level at PZ-15B apparently occurred on 25 March; therefore, it appears the response time was about four days.

The measured water levels in PZ-15B appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 39. Based on the linear projection, PZ-15B should rise to El. 498.8 when the pool rises to the spillway crest at El. 610.

(13) <u>PZ-16A</u> PZ-16A is located at Sta. 9+65 and is offset 10 ft. downstream from the dam centerline as shown in Figure 11. The top of the riser pipe is at El. 630.3. The piezometer tip is located in the impervious core at El. 536.3. PZ-16A was installed in 1989 with a wick of filter sand which extends upward 8 ft. from El. 536.3 to a bentonite seal. The material influencing the piezometer tip is a dark brown SILT with sand just below the impervious core fill.

The normal average water level in PZ-16A during the winter months is about El. 541 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 41 ft. higher than normal pool which could be attributed to artesian seepage from the foundation of the dam. The normal average water level during the summer months is about El. 541 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 41 ft. higher than normal pool which could be attributed to artesian seepage from the foundation of the dam. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 14. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 21.

Based on the March 1990 flood event shown in Figure 21, the following performance was noted. The water level in PZ-16A rose from its average level about 16 ft. to El. 547.5 compared to a pool increase of about 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-16B water levels fell from a peak level on 22 March to lower levels through 29 March. The peak water level at PZ-16A apparently occurred on 22 March; therefore, it appears the response time was about two days.

The measured water levels in PZ-16A appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 40. Based on the linear projection, PZ-16A should rise to El. 546.2 when the pool rises to the spillway crest at El. 610.

(14) PZ-16B PZ-16B is located at Sta. 9+65 and is offset 10 ft. downstream from the dam centerline as shown in Figure 11. The top of the riser pipe is at El. 630.3. The piezometer tip is located in the bedrock at El. 526.3. PZ-16A was installed in 1989 with a wick of filter sand which extends upward 4 ft. from El. 526.3 to a bentonite seal. The material influencing the piezometer tip is bedrock below the impervious core.

The normal average water level in PZ-16B during the winter months is about El. 531 as noted in Table II for normal river levels ranging from El. 498 to 502. This water level is about 31 ft. higher than normal pool which could be attributed to artesian seepage from the foundation of the dam. The normal average water level during the summer months is about El. 530 as noted in Table II for normal river levels ranging from El. 478 to 482. This water level is about 30 ft. higher than normal pool which again could be attributed to artesian seepage from the foundation of the dam. Based on the limited data available, the piezometer did respond to changes in pool elevation as shown in Figure 15. Water level measurements at Knightville Dam were taken at irregular intervals from March 1990 through November 1994. There were up to year-long periods where water level measurements were not obtained. However, for major changes in the pool level, such as the flood event of March 1990, daily readings are available and are shown on the event plot, Figure 22.

Based on the March 1990 flood event shown in Figure 22, the following performance was noted. The water level in PZ-16B rose from its average level about 6 ft. to El. 546.4 compared to a pool increase of about 69 ft. to El. 568.8. The pool data available for the March 1990 event indicates a peak pool level on 21 March and a falling pool through 29 March. PZ-16B water levels fell from a peak level on 23 March to lower levels through 29 March. The peak water level at PZ-16B apparently occurred on 23 March; therefore, it appears the response time was about one day.

The measured water levels in PZ-16B appear to respond in a nearly linear manner to changes in pool elevation as shown in Figure 41. Based on the linear projection, PZ-16B should rise to El. 542.9 when the pool rises to the spillway crest at El. 610.

(c) Profile Evaluation. Data for piezometers located on the same profile were plotted with pool elevation on time history plots. A profile along the centerline of the dam was prepared and evaluated so that seepage characteristics could be evaluated. The profile is shown in Figure 42.

The piezometric levels shown in Figure 42 indicate higher water levels at the abutments with lower levels toward the old river bed. These water levels reflect the original topographic relief in the area (i.e., river flowing through a valley). The water levels at the abutments indicate water infiltrating the embankment from the abutments. Average water levels at PZ-14A and PZ-14B, for example, were about El. 502, slightly above normal pool at El. 500, while levels at the abutments were 30 to 40 ft. higher.

(d) Cross Section Evaluations. Data for piezometers located on the same cross section were plotted with pool elevation on time history plots. Three cross sections were prepared and evaluated: Sta. 6+00, Sta. 8+75 and Sta. 10+50. The cross sections are shown in Figures 43 through 45.

(1) Station 6+00. As shown in Figure 43, water levels generally decrease from upstream to centerline along Station 6+00. As shown on Figure 16, water levels in PZ-12A and PZ-12B are approximately the same and are about 45 feet higher than normal summer pool levels indicating a natural artesian condition with seepage from the foundation strata into the shoulder fill. Average water levels in PZ-4 were even higher than PZ-12A and PZ-12B. PZ-4 is probably plugged, as

discussed in Section 4.b.(2)(b)(1). Normally it would be expected that PZ-4 water levels would be at or near the pool elevation, and PZ-12A and PZ-12B would have lower levels. There are no downstream piezometers along Station 6+00. However, Station 6+00 water levels appear to be governed by seepage from an artesian condition.

Although water levels are higher than pool levels, the piezometers generally respond to changes in pool elevation that exceed the average normal levels for each individual piezometer. For example, when the pool level rose to El. 568.8 (about 24 ft. above average levels in PZ-12A and PZ-12B) during the March 1990 flood event shown in Figure 23, PZ-12A and PZ-12B, located in the crest of the dam, rose about 3 and 4 ft. above their average levels, respectively. In other words, if the pool is below the "background" piezometric level due to artesian seepage from the dam foundation, then the piezometer generally does not respond to changes in pool level. However, when the pool level exceeds the "background" piezometric level, the piezometer generally responds to changes in the pool elevation.

(2) <u>Station 8+75.</u> As shown in Figure 44, water levels generally decrease from upstream to downstream along Station 8+75. Water levels in upstream piezometers PZ-13A, PZ-13B, PZ-14A and PZ-14B were generally higher than normal pool level as shown in Figures 18 and 19, indicating possible artesian conditions below the dam which would result in seepage into the embankment. Normally it would be expected that upstream water levels would be at or near the pool elevation, and downstream piezometers would have lower levels. However, water levels in the upstream piezometers appear to be governed by seepage through the foundation strata or trapped water which infiltrated the embankment from abutment areas.

Average normal water levels in downstream piezometers PZ-8, PZ-9, PZ-15A and PZ-15B were lower than normal pool level, which is consistent with the expected normal seepage pattern through the dam. However, the piezometers are placed very close to a horizontal layer of pervious fill which appears to act as a partial pressure relief. This observation is based on the placement of the piezometers combined with the relatively small increase in total head which was predicted for a full pool. For example, in winter conditions, the full pool at El. 610 represents an 110 ft. increase in total head. At the four downstream piezometer locations, the predicted head increase ranges from 3.0 to 6.8 ft., less than 6 percent of pool increase. At PZ-14A and PZ14-B, located in the centerline of the dam, the predicted increase in total head represents about 22 percent of the pool increase indicating a larger increase in piezometric level at the centerline of the dam than downstream. Therefore, some drainage appears to be occurring in the downstream horizontal layer.

Although upstream piezometric levels were higher than pool levels, the upstream piezometers generally responded to changes in pool elevation that exceed the normal "background" levels for each individual piezometer. For example, at the peak pool level measured during the March 1990 flood event shown in Figures 24 through 26 (pool level from 39 to 66 ft. higher than background piezometric levels), PZ-13A rose about 43 ft., PZ-13B rose about 28 ft., PZ-14A rose about 10 ft. and PZ-14B rose about 12 ft. However, downstream piezometers PZ-8, PZ-9, PZ-15A and PZ-15B typically responded only very slightly to major changes in pool levels. This type of response would be expected for a properly functioning dam (seepage along the downstream face of the core carried away by the drainage layer).

(2) Station 10+50. As shown in Figure 45, water levels along Station 10+50 do not decrease from upstream to centerline as expected. Upstream piezometer PZ-11 was dry during normal pool

levels and the flood event of March 1990. PZ-11 appears to be plugged at the tip, and provides erroneous readings. Average normal water levels in PZ-16A and PZ-16B were generally higher than normal pool level as shown in Figure 20, indicating an artesian condition beneath the embankment. Normally it would be expected that upstream water levels would be at or near the pool elevation, and downstream piezometers would have lower levels. However, water levels in the PZ-16A and PZ-16B appear to be governed by seepage through the bedrock.

Although piezometric levels were higher than pool levels, PZ-16A and PZ-16B generally responded to changes in pool elevation that exceed the normal "background" levels for each individual piezometer. For example, at the peak pool level measured during the March 1990 flood event shown in Figure 27 (pool level 28 to 30 ft. higher than background piezometric levels), PZ-16A and PZ-16B rose about 1 ft.

(e) Phreatic Surface Elevation Plan. The phreatic surface elevation contours for average winter piezometric levels above the bedrock are shown in Figure 46. The plot includes data for piezometers located in the foundation soil strata of the dam. The data indicates that the old river channel is acting as a drain for the right and left abutment of the structure.

Contours were also generated for the average summer piezometric levels. The summer contour plan was very similar to the winter contour plan. The same general trends were exhibited, although the piezometric levels were about 10 ft. lower on the left abutment and only slightly lower at other locations beneath the right abutment and centerline of dam. Piezometric levels were approximately the same along the central section of the dam (Station 8+75). The similarity of the two phreatic surfaces indicates that piezometric behavior is consistent year round, with water levels slightly decreased in the summer. Thus, piezometric patterns in the longitudinal profile and cross sections of the dam would be similar to their winter patterns, but lower in elevation.

c. Strong Motion Accelerographs

(1) Data Collection. The U.S. Army Corps of Engineers Waterways Experimentation Station (WES) maintains all of the New England Division's (NED) strong motion instruments. WES personnel inspect each site twice per year as part of a maintenance and repair program. A mandatory monthly visual inspection by Knightville Dam personnel is performed to check the A-C power inside each shelter and to record the electromechanical counter reading at each instrument. The findings are recorded on a standard form and mailed each month to Geotechnical Engineering Division (GED).

In the event of an earthquake and in accordance with ER 110-2-1802, GED directs Knightville Dam personnel to read the counter and perform a visual inspection of the project. Based on this inspection and the intensity of the event, an engineering team may be dispatched to perform a visual inspection and the Office of the Chief of Engineers (OCE) is advised.

WES is also notified in order for them to retrieve the earthquake record from the activated accelerographs. GED is required to produce an Earthquake Incident Report of the event.

(2) Interpretation and Evaluation. Knightville Dam has experienced four significant seismic events since the accelerographs were installed in 1976. The accelerographs have been activated once during a seismic event. The accelerographs were tripped by the Blue Mountain N.Y.

event in October 1983 but the accelerations were insignificant and no values were reported by WES. A summary of the historic seismic data is presented in Table III.

5. Conclusions and Recommendations

a. General. Geotechnical instrumentation at Knightville Dam consists of seven crest survey monuments and four control points for vertical and horizontal control, three strong motion accelerograph instruments, four settlement gauge/piezometers installed during construction of the dam and ten piezometers installed in 1989. All instrumentation appears to be functioning adequately with the exception of PZ-4 and PZ-11. Instrumentation measurements typically are consistent with expected behavior.

b. Crest Monuments.

(1) Schedule. The schedule for crest monument surveys at Knightville Dam is presently once every five years to coincide with the periodic inspection schedule. The next periodic inspection is scheduled for FY 99, therefore, the next crest monument survey should be performed in FY 98 to insure that the data collected can be presented in the sixth periodic inspection report. If unusual readings are obtained during the next survey or if field evidence of embankment movement is found, the reading schedule will be adjusted as needed.

(2) Evaluation of Adequacy. Total settlement of all bounds was limited to less than 0.04 ft. over a six-year period. This settlement could be attributed to the survey accuracy, settlement

of the embankment or to the settlement of the bound itself. This small amount of settlement is considered tolerable.

Based on the data which have been obtained to date, it is concluded that there has been no significant vertical movement of the embankment and apparent movements may be due to limitations and accuracy of measurement.

The present configuration and number of crest monuments and control points are considered adequate to monitor horizontal and vertical movement of the dam embankment. With the advent of Global Positioning Systems Survey (GPS) such as NAVSTAR, the accuracy of three-dimensional movements can be detected at levels of less than 5 millimeters (Ref. ETL 1110-1-133). The implementation of this type of monitoring system within the next five years is recommended if it proves to be cost effective.

c. Piezometers

(1) General. Piezometers are used to measure groundwater levels and pore pressures both in the foundation and embankments of earth and rockfill dams. Experience has shown that the installation of piezometers in earth fills and their foundation provides significant data indicating the magnitude and distribution of pore pressure. Seepage patterns, zones of potential piping, and the performance of seepage control measures may be identified from piezometer levels. It should be noted that a "dry" reading can provide important information and must be included in a piezometer reading report.

(2) Evaluation of Adequacy. The existing piezometers at Knightville Dam are considered adequate to evaluate the performance of the embankment, foundation cutoff and grout curtain. However, a more thorough evaluation could be made if the reading schedule were followed and the piezometers read more frequently.

Two of the original piezometers, PZ-4 and PZ-11, may not be accurate. For example, PZ-11 is typically dry independent of the pool elevation while PZ-4 is either dry or registers exceptionally high levels. Falling head permeability tests performed during a site visit conducted on 9 June 1995 indicated that the piezometer tips are probably plugged. This conclusion should be verified and if the piezometers are determined to be faulty, they should be abandoned and replaced with piezometers similar to those installed in 1989. These piezometers appeared to be functioning properly when the previous Instrumentation Appendix was published in 1989.

d. Strong Motion Accelerographs

(1) General. Since their installation in 1976, the strong motion accelerographs at Knightville Dam have experienced four significant events and have been activated once, in 1983, by the Blue Mountain, New York earthquake. The records from this event showed small accelerations and Waterways Experimentation Station did not make a report of the results.

(2) Schedule. The present schedule for reading all strong motion accelerographs at Knightville Dam is once per month. In the past, this schedule has been maintained very well and there is a good database of information for accelerographs. The present schedule is adequate and should be maintained.

(3) Evaluation of Adequacy. The present level of strong motion instrumentation is adequate to monitor movement of the embankment and foundation in the event of an earthquake. The maintenance of current equipment is recommended and no supplemental accelerographs are recommended at this time.

F:\11163\006\KVILLE\KVILLE.WPF

TABLE I
PIEZOMETER SUMMARY
KNIGHTVILLE DAM

PIEZOMETER NUMBER	APPROXIMATE STATION	APPROXIMATE CENTERLINE OFFSET	TOP OF RISER PIPE ELEVATION	PIEZOMETER TIP ELEVATION	ZONE LOCATED	MATERIAL AT TIP ELEVATION
PZ-4	6+00	190 U/S	569.3	531.0 (2)	FOUNDATION	N/A
PZ-8	8+75	90 U/S	604.7	473.6 (2)	FOUNDATION	N/A
PZ-9	8+75	190 D/S	568.8	475.4 (3)	FOUNDATION	N/A
PZ-11	11+00	90 U/S	603.2	549.2 (2)	SHOULDER FILL	N/A
PZ-12A	6+00	10 D/S	630.3	521.3	IMPERV. CORE	Medium br. SILT w/ sand (22)
PZ-12B	6+00	10 D/S	630.3	509.3	FOUNDATION	Medium br. silty (30-40) SAND w/ gravel (5-1
PZ-13A	7+90	120 U/S	598.5	477.4	SHOULDER FILL	Lt. br. silty (15-25) SAND w/ gravel
PZ-13B	7+90	120 U/S	598.5	445.5	FOUNDATION	Bedrock
PZ-14A	8+40	10 D/S	629.9	474.0	FOUNDATION	Medium br. silty (12) SAND and GRAVEL
PZ-14B	8+40	10 D/S	629.9	462.0	FOUNDATION	Bedrock
PZ-15A	8+75	135 D/S	589.8	478.9	SHOULDER FILL	Medium br. silty (5-15) SAND
PZ-15B	8+75	135 D/S	589.8	462.5	FOUNDATION	Bedrock
PZ-16A	9+65	10 D/S	630.3	536.3	IMPERV. CORE	Dk. br. SILT w/ sand (20)
PZ-16B	9+65	10 D/S	630.3	526.3	FOUNDATION	Bedrock

Notes:
1. All elevations are in feet and referenced to the National Geodetic Vertical Datum of 1929 (NGVD).
2. Piezometer tip elevation corresponds to sounding elevation performed in 1988.
3. Riser pipe appears to be blocked at elevation shown, elevation does not reflect actual bottom.

19-Jul-95

F:\11163\006\kville\task8.wb2

HALEY & ALDRICH, INC.

TABLE II
KNIGHTVILLE DAM
PIEZOMETER DATA

DATE	POOL STAGE	POOL EL.	PIEZOMETRIC LEVEL, FT NGVD													
			PZ-4	PZ-8	PZ-9	PZ-11	PZ-12A	PZ-12B	PZ-13A	PZ-13B	PZ-14A	PZ-14B	PZ-15A	PZ-15B	PZ-16A	PZ-16B
		TIP EL.	531.0	473.6	475.4	549.2	521.3	509.3	477.4	445.5	474.0	462.0	478.9	462.5	536.3	526.3
19-Mar-90	75.6	555.6	NA	493.2	485.5	DRY	527.9	527.6	535.6	527.3	514.4	515.2	491.8	490.7	540.8	504.7
20-Mar-90	73.5	553.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
21-Mar-90	88.8	568.8	NA	493.7	486.0	DRY	531.8	530.7	562.6	543.2	513.2	514.7	493.6	492.7	532.0	542.0
22-Mar-90	85.6	565.6	564.6	494.0	486.4	DRY	515.6	513.6	562.6	543.1	512.3	514.4	494.7	493.5	547.5	543.2
23-Mar-90	69.9	549.9	560.7	494.8	487.1	DRY	521.3	527.0	551.7	538.5	511.4	513.5	496.1	494.0	540.3	546.4
24-Mar-90	59.6	539.6	557.7	495.2	487.5	DRY	533.0	534.2	544.3	531.1	510.0	511.8	496.9	494.2	544.8	537.6
25-Mar-90	35.5	515.5	556.8	495.9	488.0	DRY	532.0	533.2	534.4	523.0	508.7	507.7	497.4	497.2	539.4	532.9
26-Mar-90	18.6	498.6	555.7	496.4	488.3	DRY	531.4	532.3	528.6	517.3	506.3	506.2	497.3	493.4	542.0	531.3
27-Mar-90	25.5	505.5	554.5	500.0	489.1	DRY	530.9	531.6	526.1	516.7	505.4	505.5	497.0	493.2	541.7	530.7
28-Mar-90	19.0	499.0	553.3	497.0	488.5	DRY	530.7	531.0	523.7	514.7	504.6	504.8	496.7	493.0	541.6	530.6
29-Mar-90	17.7	497.7	551.9	497.1	488.4	DRY	530.4	530.5	521.2	513.1	503.7	504.1	496.6	492.8	541.5	530.4
01-May-90	3.9	483.9	535.3	496.2	487.1	DRY	528.4	527.7	505.8	504.0	497.7	501.7	492.9	490.5	540.8	529.9
01-Aug-90	0.9	480.9	DRY	491.0	484.5	DRY	527.6	526.5	491.8	495.4	493.4	491.8	489.2	491.1	540.5	529.8
02-Oct-90	1.5	481.5	DRY	490.5	474.3	DRY	527.5	526.3	492.0	495.6	493.4	491.7	488.9	487.6	540.4	529.9
02-Nov-90	3.5	483.5	546.6	490.8	484.8	DRY	527.6	526.5	506.1	503.6	497.1	496.2	490.1	489.1	540.4	529.9
03-Jan-91	21.8	501.8	DRY	494.5	484.8	DRY	527.5	526.6	506.7	512.1	497.3	496.7	490.1	489.4	540.3	529.9
01-Jul-91	1.1	481.1	DRY	490.5	484.2	584.2	527.4	526.3	492.6	496.0	493.5	491.9	487.9	488.9	540.3	529.9
25-Aug-92	1.4	481.4	541.4	490.1	484.2	DRY	527.2	526.3	495.2	498.1	494.0	492.8	489.0	488.1	540.3	530.0
04-Sep-92	2.3	482.3	536.7	490.2	485.3	DRY	527.3	526.4	494.5	497.5	493.9	492.6	489.0	488.1	540.3	530.0
06-Oct-92	0.9	480.9	537.0	490.2	485.3	DRY	527.6	526.4	494.5	498.4	493.8	492.6	489.0	488.1	540.3	530.1
30-Mar-93	79.3	559.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01-Apr-93	88.1	568.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
04-Apr-93	85.3	565.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
06-Apr-93	62.7	542.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
14-Apr-93	88.2	568.2	567.0	499.5	489.6	549.2	536.9	537.1	564.8	545.3	517.2	518.3	500.8	498.0	550.0	543.1
16-Apr-93	77.0	557.0	558.2	500.7	490.4	549.4	539.2	540.0	555.4	539.3	515.6	520.5	502.2	498.5	547.9	540.7
19-Apr-93	89.8	569.8	NA	502.2	491.4	549.6	539.7	543.0	566.8	547.0	519.5	521.2	503.9	499.8	551.6	544.0

TABLE II
KNIGHTVILLE DAM
PIEZOMETER DATA

DATE	POOL STAGE	POOL EL.	PZ-4	PZ-8	PZ-9	PZ-11	PZ-12A	PZ-12B	PZ-13A	PZ-13B	PZ-14A	PZ-14B	PZ-15A	PZ-15B	PZ-16A	PZ-16B
			PIEZOMETRIC LEVEL, FT NGVD													
		TIP EL.	531.0	473.6	475.4	549.2	521.3	509.3	477.4	445.5	474.0	462.0	478.9	462.5	536.3	526.3
26-May-93	3.0	483.0	536.5	498.6	488.0	DRY	529.5	528.4	502.3	501.2	498.9	497.6	495.0	491.6	534.8	530.4
09-Jun-93	1.4	481.4	DRY	494.4	487.7	DRY	528.4	529.5	502.3	501.4	499.4	497.7	494.7	491.7	541.3	530.5
01-Jul-93	0.4	480.4	DRY	491.0	484.4	DRY	527.6	526.6	491.0	494.8	493.5	491.8	489.2	488.1	540.8	530.6
04-Aug-93	0.4	480.4	DRY	491.0	484.4	DRY	527.6	526.5	491.0	494.8	493.4	491.8	489.2	488.0	541.0	530.5
13-Sep-93	0.4	480.4	DRY	490.9	484.3	DRY	527.6	526.1	490.8	494.8	493.3	491.7	489.1	488.0	540.7	530.4
08-Oct-93	0.4	480.4	DRY	501.0	484.4	DRY	527.8	526.1	490.8	495.1	493.3	491.8	489.1	488.1	540.7	530.5
01-Nov-93	2.5	482.5	DRY	490.8	484.8	DRY	527.6	526.5	496.1	496.2	495.0	493.8	490.1	489.1	540.4	529.9
19-Apr-94	72.0	552.0	532.1	492.6	489.2	551.2	529.3	528.9	546.4	533.1	508.4	509.0	492.8	492.9	541.8	537.4
25-May-94	3.7	483.7	DRY	494.1	486.1	551.2	527.7	526.9	501.0	500.7	497.5	495.8	491.5	490.2	540.5	531.2
22-Jun-94	1.2	481.2	DRY	499.4	489.4	DRY	533.0	533.3	536.1	532.2	510.8	513.9	496.2	496.7	544.4	531.5
21-Jul-94	1.4	481.4	DRY	499.7	489.2	DRY	534.1	533.8	535.8	532.2	510.9	514.2	496.7	496.8	544.7	531.6
25-Aug-94	1.4	481.4	DRY	491.0	484.6	DRY	530.8	529.3	529.0	527.3	505.2	505.8	494.0	493.6	540.8	526.6
28-Sep-94	6.5	486.5	530.9	489.7	483.8	551.9	527.4	526.1	490.8	495.2	492.8	491.4	488.5	487.5	540.5	531.3
24-Oct-94	1.5	481.5	DRY	490.2	484.0	552.0	527.4	526.2	490.9	495.4	493.0	491.8	488.8	487.8	540.7	531.2
23-Nov-94	2.8	482.8	DRY	494.5	484.8	552.1	527.5	526.6	492.0	495.6	493.4	491.7	490.4	487.6	540.7	531.3
AVERAGE LEVEL DURING WINTER POOL (2)			554.5	496.0	487.2	DRY	529.8	530.0	519.6	514.7	502.7	502.6	494.7	491.9	541.3	530.6
AVERAGE LEVEL DURING SUMMER POOL (2)			539.2	492.9	484.6	568.1	528.7	527.8	501.7	503.7	497.2	496.5	490.8	490.2	541.2	530.2

NOTES:
1. NA DENOTES PIEZOMETRIC LEVEL NOT AVAILABLE.
2. AVERAGE PIEZOMETRIC LEVEL DURING WINTER POOL IS BASED ONLY ON READINGS WHEN THE POOL LEVEL FALLS BETWEEN EL. 498 AND 502.
3. AVERAGE PIEZOMETRIC LEVEL DURING SUMMER POOL IS BASED ONLY ON READINGS WHEN THE POOL LEVEL FALLS BETWEEN EL. 478 AND 482.

19-Jul-95

F:\11163\006\KVILLE\KVTASK6.WB2

TABLE III
KNIGHTVILLE DAM
PIEZOMETER DATA

DATE	POOL STAGE	PIEZOMETER READINGS, DEPTH IN METERS													
		PZ-4	PZ-8	PZ-9	PZ-11	PZ-12A	PZ-12B	PZ-13A	PZ-13B	PZ-14A	PZ-14B	PZ-15A	PZ-15B	PZ-16A	PZ-16B
19-Mar-90	75.6	NA	34.0	25.4	DRY	31.2	31.3	19.2	21.7	35.2	35.0	29.9	30.2	27.3	38.3
19-Mar-90	75.6	NA	34.0	25.4	DRY	31.2	31.3	19.2	21.7	35.2	35.0	29.9	30.2	27.3	38.3
20-Mar-90	73.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
21-Mar-90	88.8	NA	33.8	25.2	DRY	30.0	30.3	10.9	16.9	35.6	35.1	29.3	29.6	30.0	26.9
22-Mar-90	85.6	1.4	33.7	25.1	DRY	35.0	35.6	10.9	16.9	35.8	35.2	29.0	29.4	25.2	26.6
23-Mar-90	69.9	2.6	33.5	24.9	DRY	33.2	31.5	14.3	18.3	36.1	35.5	28.6	29.2	27.4	25.6
24-Mar-90	59.6	3.6	33.4	24.8	DRY	29.7	29.3	16.5	20.5	36.6	36.0	28.3	29.2	26.1	28.3
25-Mar-90	35.5	3.8	33.2	24.6	DRY	30.0	29.6	19.5	23.0	36.9	37.3	28.2	28.2	27.7	29.7
26-Mar-90	18.6	4.2	33.0	24.6	DRY	30.1	29.9	21.3	24.7	37.7	37.7	28.2	29.4	26.9	30.2
27-Mar-90	25.5	4.5	31.9	24.3	DRY	30.3	30.1	22.1	24.9	38.0	37.9	28.3	29.5	27.0	30.3
28-Mar-90	19.0	4.9	32.8	24.5	DRY	30.4	30.3	22.8	25.5	38.2	38.1	28.4	29.5	27.0	30.4
29-Mar-90	17.7	5.3	32.8	24.5	DRY	30.5	30.4	23.6	26.0	38.5	38.4	28.4	29.6	27.1	30.4
01-May-90	3.9	10.4	33.1	24.9	DRY	31.1	31.3	28.3	28.8	40.3	39.1	29.6	30.3	27.3	30.6
01-Aug-90	0.9	DRY	34.7	25.7	DRY	31.3	31.6	32.5	31.4	41.6	42.1	30.7	30.1	27.4	30.6
02-Oct-90	1.5	DRY	34.8	28.8	DRY	31.3	31.7	32.4	31.4	41.6	42.1	30.8	31.2	27.4	30.6
02-Nov-90	3.5	6.9	34.7	25.6	DRY	31.3	31.6	28.2	28.9	40.5	40.8	30.4	30.7	27.4	30.6
03-Jan-91	21.8	DRY	33.6	25.6	DRY	31.3	31.6	28.0	26.3	40.4	40.6	30.4	30.6	27.4	30.6
01-Jul-91	1.1	DRY	34.8	25.8	5.8	31.4	31.7	32.3	31.2	41.6	42.1	31.1	30.8	27.4	30.6
25-Aug-92	1.4	8.5	34.9	25.8	DRY	31.4	31.7	31.5	30.6	41.4	41.8	30.7	31.0	27.4	30.6
04-Sep-92	2.3	9.9	34.9	25.5	DRY	31.4	31.7	31.7	30.8	41.5	41.9	30.7	31.0	27.4	30.6
06-Oct-92	0.9	9.9	34.9	25.5	DRY	31.3	31.7	31.7	30.5	41.5	41.9	30.8	31.0	27.4	30.6
30-Mar-93	79.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01-Apr-93	88.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
04-Apr-93	85.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
06-Apr-93	62.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
14-Apr-93	88.2	0.7	32.1	24.1	16.5	28.5	28.4	10.3	16.2	34.4	34.0	27.2	28.0	24.5	26.6
16-Apr-93	77.0	3.4	31.7	23.9	16.4	27.8	27.5	13.1	18.0	34.9	33.4	26.7	27.8	25.1	27.3
19-Apr-93	89.8	NA	31.3	23.6	16.4	27.6	26.6	9.7	15.7	33.7	33.2	26.2	27.5	24.0	26.3
26-May-93	3.0	10.0	32.4	24.6	DRY	30.7	31.1	29.3	29.6	39.9	40.3	28.9	29.9	29.1	30.5

TABLE III
KNIGHTVILLE DAM
PIEZOMETER DATA

DATE	POOL STAGE	PIEZOMETER READINGS, DEPTH IN METERS													
		PZ-4	PZ-8	PZ-9	PZ-11	PZ-12A	PZ-12B	PZ-13A	PZ-13B	PZ-14A	PZ-14B	PZ-15A	PZ-15B	PZ-16A	PZ-16B
19-Mar-90	75.6	NA	34.0	25.4	DRY	31.2	31.3	19.2	21.7	35.2	35.0	29.9	30.2	27.3	38.3
09-Jun-93	1.4	DRY	33.6	24.7	DRY	31.1	30.7	29.3	29.6	39.8	40.3	29.0	29.9	27.1	30.4
01-Jul-93	0.4	DRY	34.6	25.7	DRY	31.3	31.6	32.7	31.6	41.6	42.1	30.7	31.0	27.3	30.4
04-Aug-93	0.4	DRY	34.7	25.7	DRY	31.3	31.6	32.8	31.6	41.6	42.1	30.7	31.0	27.2	30.4
13-Sep-93	0.4	DRY	34.7	25.8	DRY	31.3	31.7	32.8	31.6	41.7	42.1	30.7	31.0	27.3	30.5
08-Oct-93	0.4	DRY	31.6	25.7	DRY	31.2	31.7	32.8	31.5	41.6	42.1	30.7	31.0	27.3	30.4
01-Nov-93	2.5	DRY	34.7	25.6	DRY	31.3	31.6	31.2	31.2	41.1	41.5	30.4	30.7	27.4	30.6
19-Apr-94	72.0	11.3	34.2	24.3	15.9	30.8	30.9	15.9	19.9	37.1	36.9	29.6	29.6	27.0	28.3
25-May-94	3.7	DRY	33.7	25.2	15.8	31.3	31.5	29.7	29.8	40.4	40.9	30.0	30.4	27.4	30.2
22-Jun-94	1.2	DRY	32.1	24.2	DRY	29.6	29.6	19.0	20.2	36.3	35.4	28.5	28.4	26.2	30.1
21-Jul-94	1.4	DRY	32.0	24.3	DRY	29.3	29.4	19.1	20.2	36.3	35.3	28.4	28.4	26.1	30.1
25-Aug-94	1.4	DRY	34.7	25.7	DRY	30.3	30.8	21.2	21.7	38.0	37.8	29.2	29.3	27.3	31.6
28-Sep-94	6.5	11.7	35.1	25.9	15.7	31.4	31.7	32.8	31.5	41.8	42.2	30.9	31.2	27.4	30.2
24-Oct-94	1.5	DRY	34.9	25.8	15.6	31.3	31.7	32.8	31.4	41.7	42.1	30.8	31.1	27.3	30.2
23-Nov-94	2.8	DRY	33.6	25.6	15.6	31.3	31.6	32.4	31.4	41.6	42.1	30.3	31.2	27.3	30.2

NOTES:
1. NA DENOTES PIEZOMETER READING NOT AVAILABLE.

19-Jul-95

F:\11163\006\KVILLE\KVTASK6.WB2

HALEY & ALDRICH, INC.

FILE

HALEY & ALDRICH, INC.

TABLE IV
HISTORIC SEISMIC DATA
KNIGHTVILLE DAM

SEISMIC EVENT	DISTANCE TO CENTER	INTENSITY AT CENTER (1)	RECORDED ACCELERATION AT DAM	ESTIMATED ACCELERATION AT DAM
Grand Falls, N.B., Canada (1/09/82)	306 mi.	7.4 (R = 5.8)	N/A	N/A
Gaza, New Hampshire (1/19/82)	11 mi.	5.2 (R = 4.7)	N/A	N/A
Blue Mountain, New York (10/07/83)	130 mi.	6.0 (R = 5.1)	NOT MEASURABLE	N/A
Franklin, New Hampshire (10/25/86)	5 mi.	3.6 (R = 3.9)	N/A	N/A
Saguenay, Quebec, Canada (11/25/88)	250 mi.	7.6 (R = 5.9)	N/A	N/A

Notes:
1. Intensities correspond to Modified Mercalli Intensity (MMI) = (2 x Richter Magnitude) - 4.2.
2. N/A denotes accelerographs not activated.

19-Jul-95

f:\11163\006\kville\task8.wb1

HALEY & ALDRICH INC.

Letter of Transmittal

Geotechnical Engineers &
Environmental Consultants

To	Department of the Army	Date	15 February 1995
	New england Division, Corps of Engineers	File Number	11163-004
	424 Trapelo Road, Waltham, MA 02254-9149	Subject	Hop Brook Dam
Attention	Mr Richard Reardon		

Copies	Date	Description
3	15 February 1995	Instrumentation Appendix to Periodic Inspection Report No. 5
1	15 February 1995	2 3.5" HD diskettes containing copies of report, tables, figures and task 6
1	15 February 1995	Past reports and additional background information

Remarks

Laura -

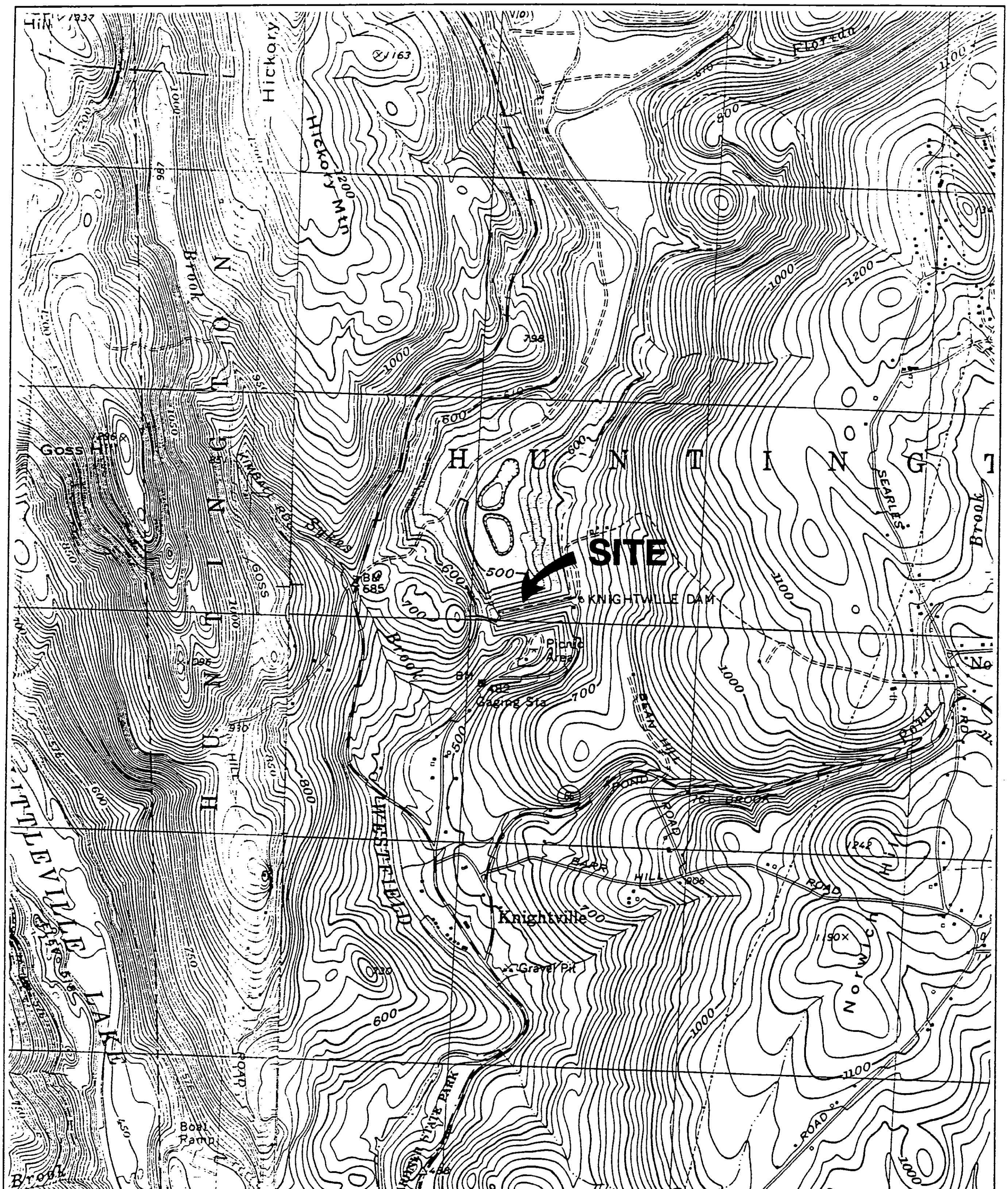
The Microstation Disks will be sent under separate cover.

Copy To

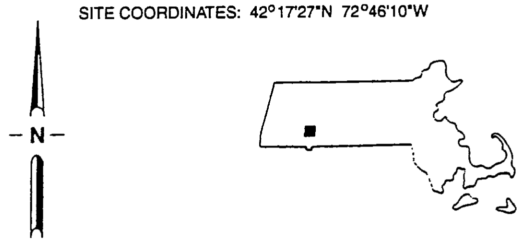
Signed Douglas A. Gifford

58 Charles Street
Cambridge, MA 02141
Tel: 617/494-1606
Fax: 617/577-8142

Offices
San Francisco, California
Denver, Colorado
Glastonbury, Connecticut
Scarborough, Maine
Silver Spring, Maryland
Bedford, New Hampshire
Rochester, New York
Cleveland, Ohio



SITE COORDINATES: 42°17'27"N 72°46'10"W



U.S.G.S. QUADRANGLE: WESTHAMPTON, MA

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

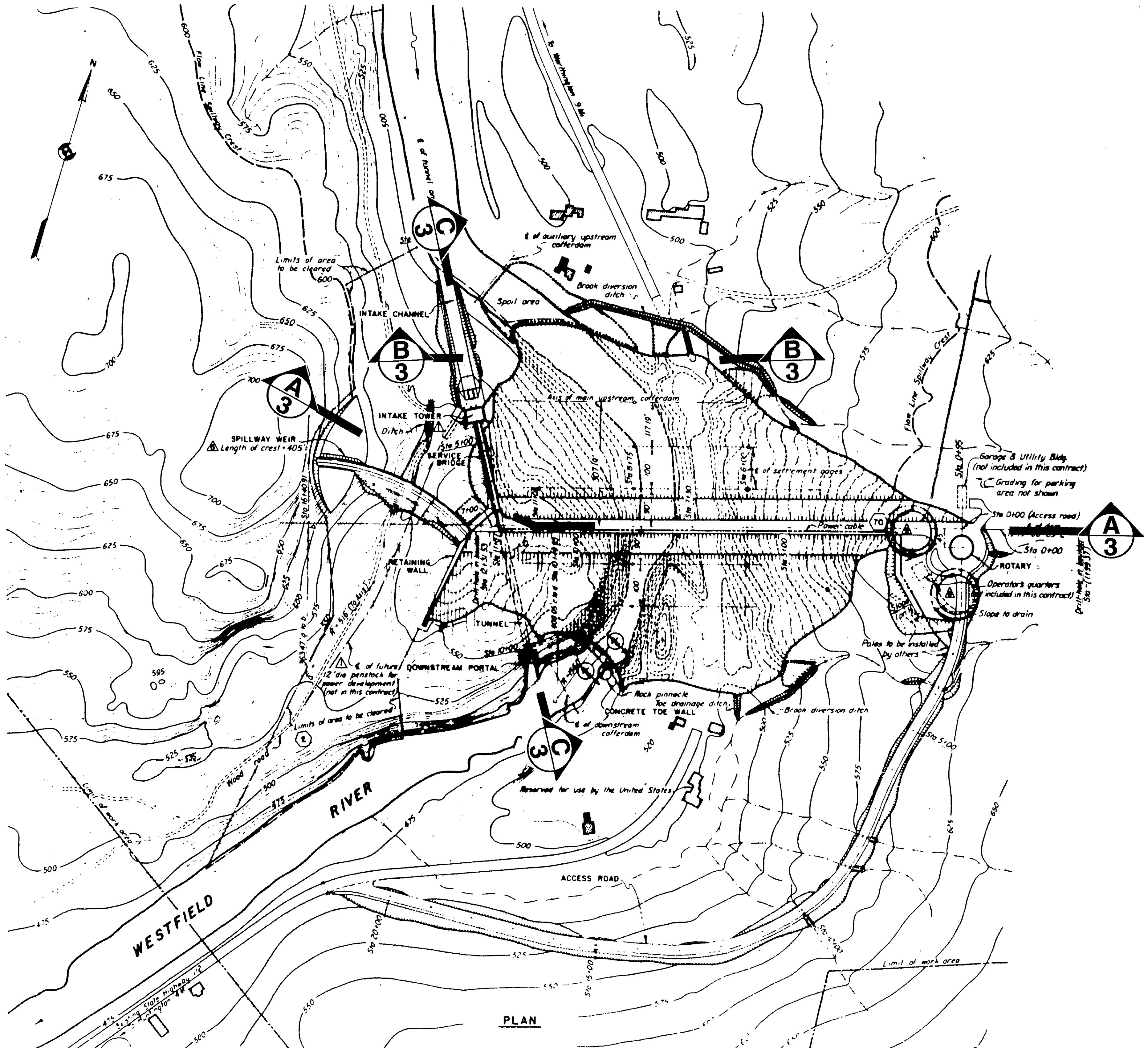
PROJECT LOCUS

APPROXIMATE SCALE: 1:25,000

JULY 1995

FILE NO. 11163-006 A52

FIGURE 1



NOTE:

1. DRAWING PROVIDED BY THE U.S. ARMY CORPS OF ENGINEERS.

HALEY & ALDRICH, INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

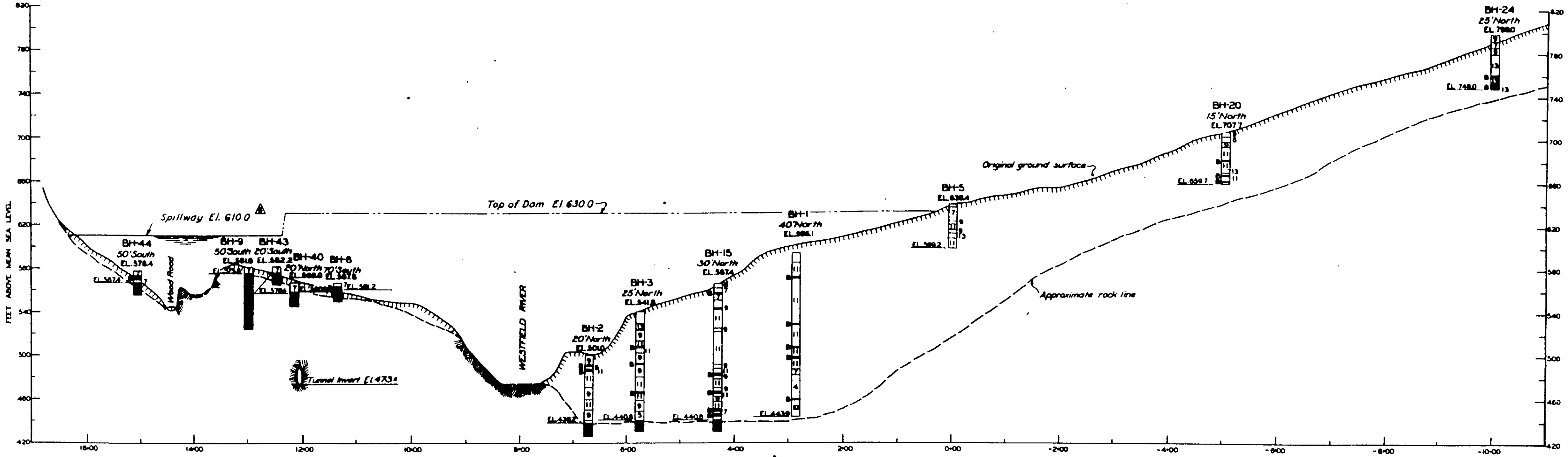
AS BUILT PLAN

SCALE: NONE

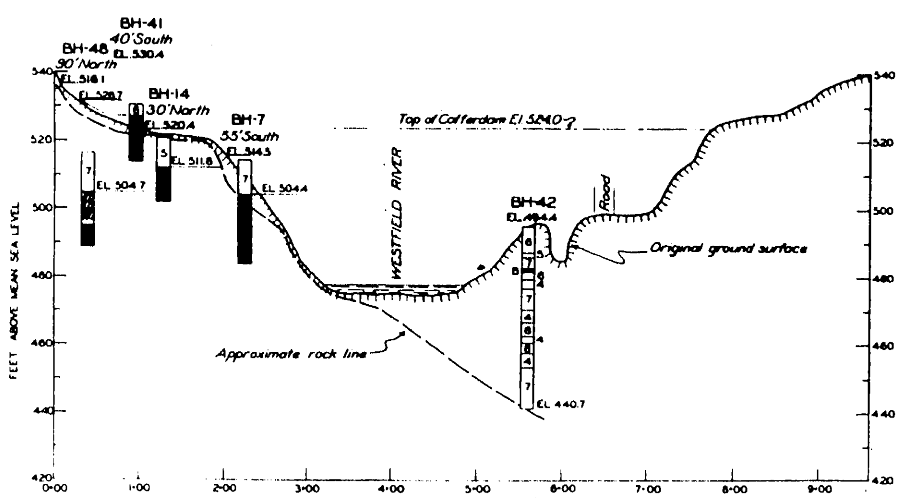
JULY 1995

11163-006 B77

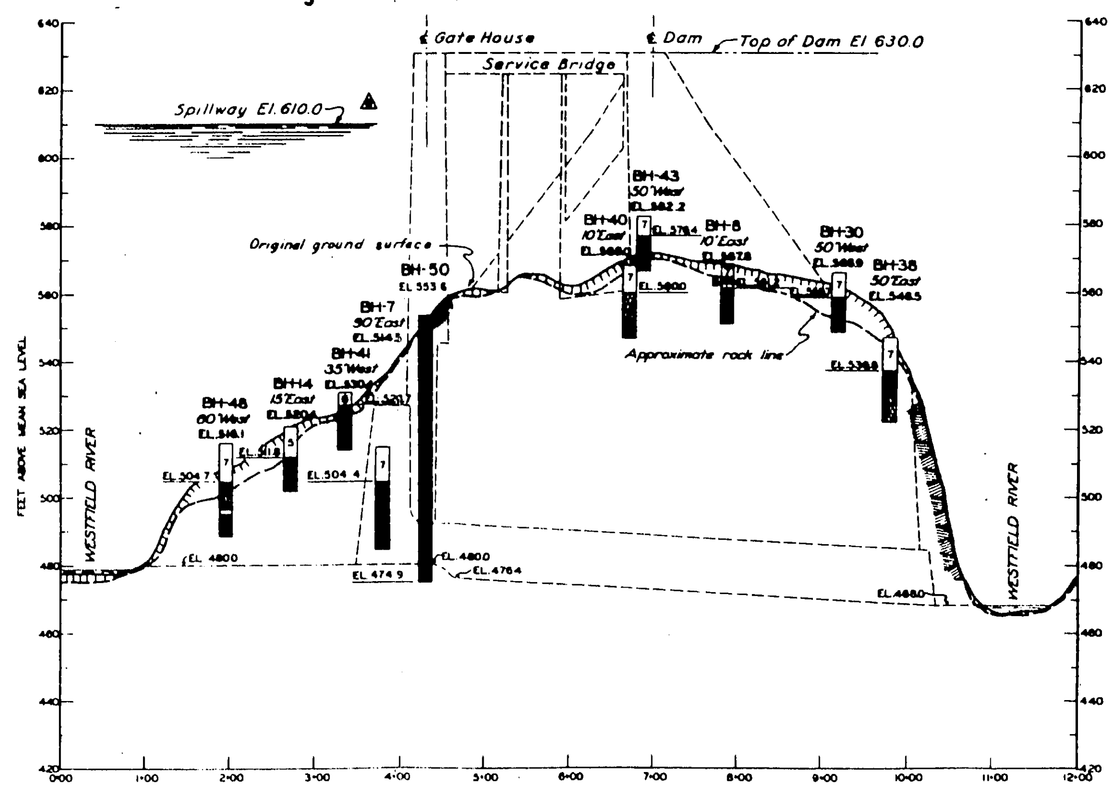
FIGURE 2



SECTION ON LINE $\frac{A}{3}$ LOOKING UPSTREAM



SECTION ON LINE $\frac{B}{3}$ -LOOKING UPSTREAM



PROFILE ON LINE $\frac{C}{3}$ CENTER LINE OF TUNNEL

NOTE:

1. DRAWING PROVIDED BY THE U.S. ARMY CORPS OF ENGINEERS.

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

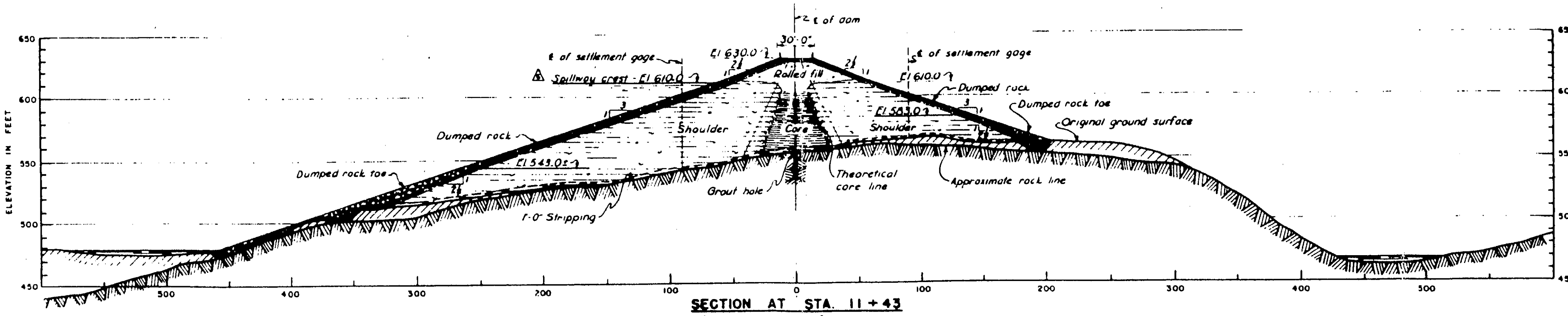
GEOLOGIC SECTIONS

SCALE: NONE

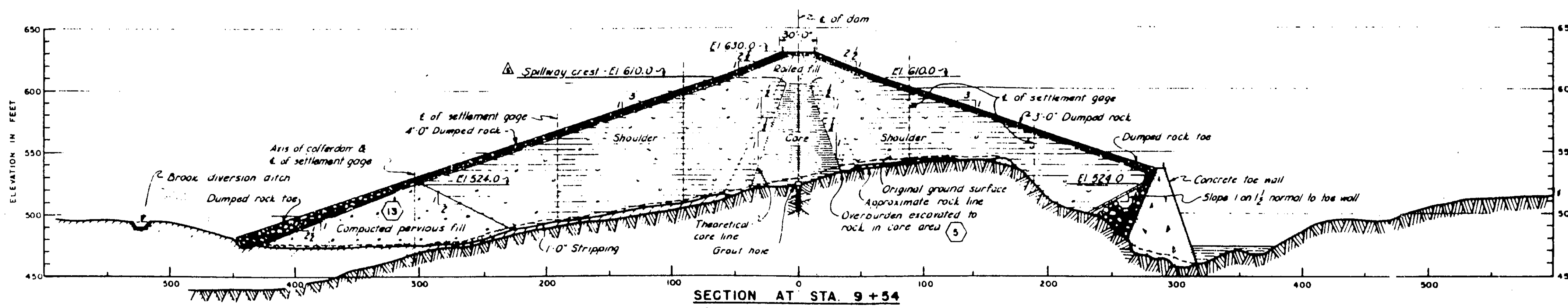
JULY 1995

11163-006 B76

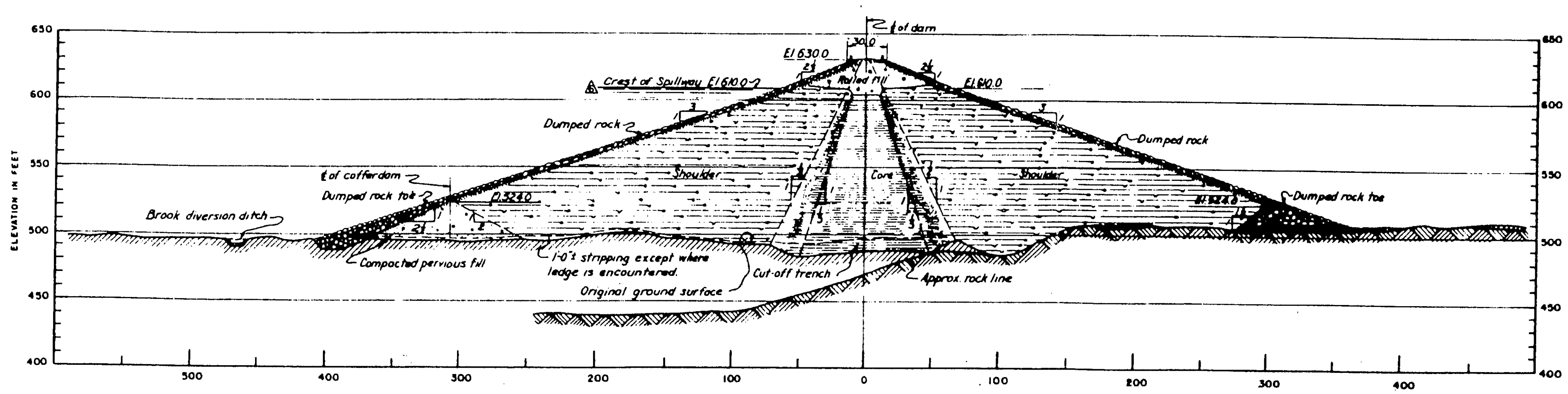
FIGURE 3



SECTION AT STA. 11+43
See enlarged detail of downstream toe on Sheet No 9
SCALE 1" = 40'



SECTION AT STA. 9+54
See enlarged detail of upstream toe on Sheet No 9
SCALE 1" = 40'



SECTION AT STA. 7+30
SCALE 1" = 40'
For enlarged detail of downstream toe see Sheet No 9

NOTES:

1. **DRAWING PROVIDED BY THE U.S. ARMY CORPS OF ENGINEERS.**

HALEY & ALDRICH, INC.
Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

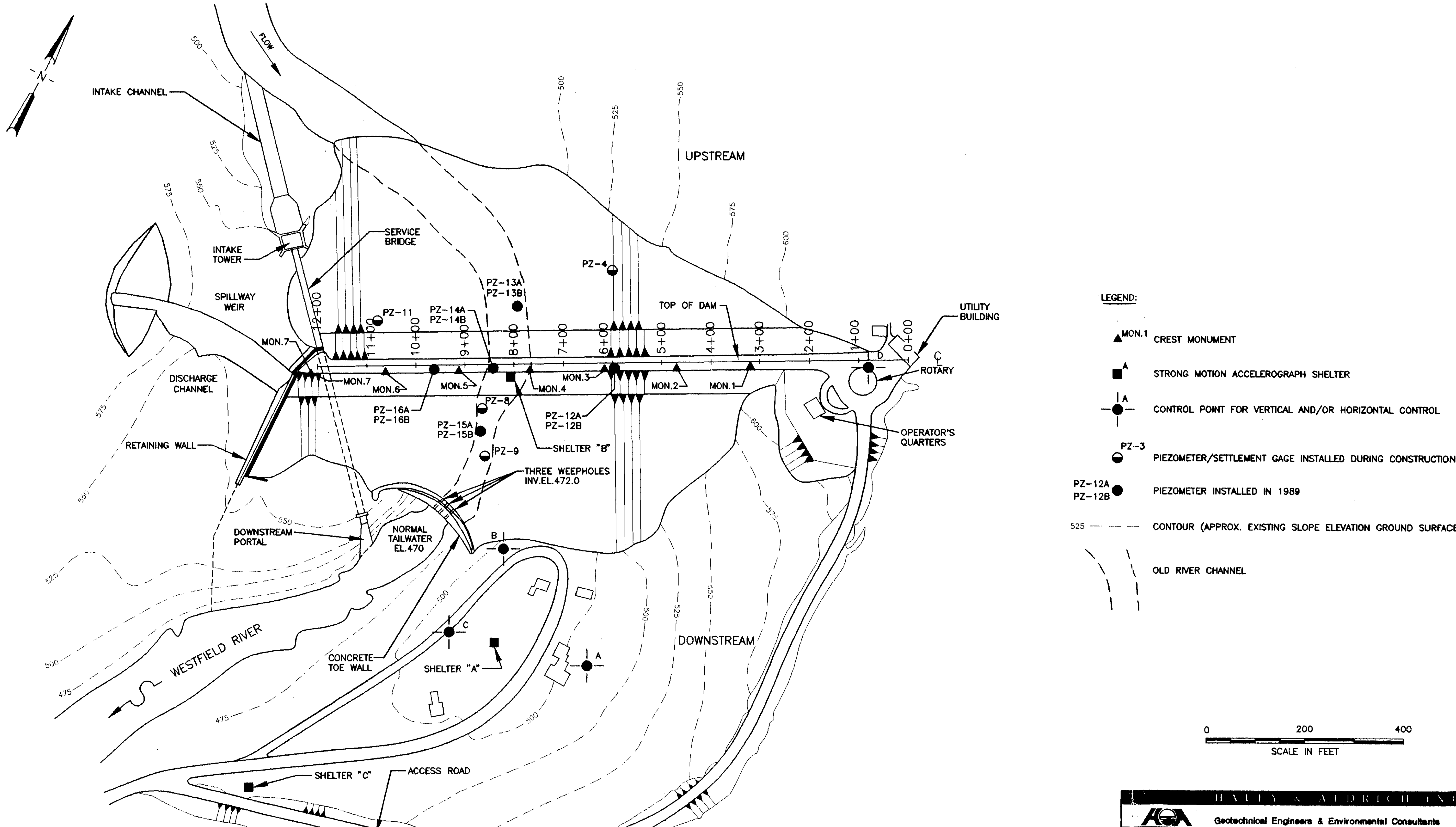
AS BUILT CROSS SECTIONS

SCALE: AS SHOWN

JULY 1995

11163-006

FIGURE 4



HALEY & ALDRICH INC

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

INSTRUMENTATION PLAN

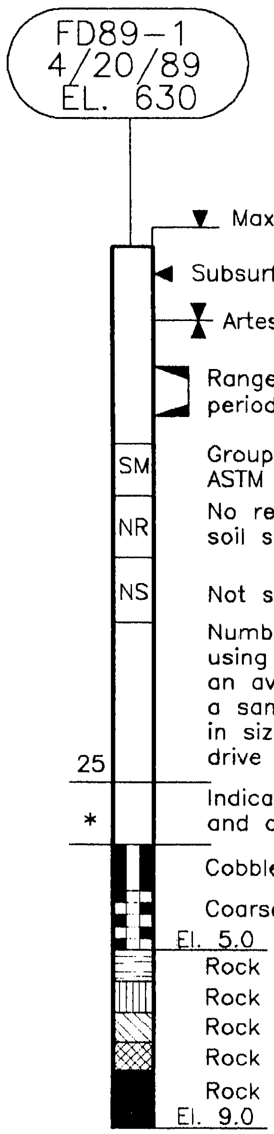
SCALE: 1" = 200'

JULY 1995

FIGURE 5

11163-006 B48

LEGEND FOR GRAPHIC LOGS



Type, year and number of exploration.

Date exploration completed.

Elevation of ground surface at time of exploration.

Maximun artesian head.

Subsurface water level.

Artesian flow encountered.

Range of subsurface water level during period of observation.

Group letter symbol according to ASTM D2487 AND ASTM D2488.

No recovery or unsatisfactory soil samples recovered.

Not sampled

Number of blows per foot of penetration using a 140 lb. hammer falling freely an average drop of 30 inches to drive a sample spoon of 2" O.D – 1-3/8" I.D. in size equipped with bevelled and sharpened drive shoe.

Indicates sample taken with a 300 lb. hammer and a drop of 18 inches.

Cobbles or boulders.

Coarse gravel or nested cobbles and boulders.

Elevation of bedrock surface.

Rock core recovery 0–25%.

Rock core recovery 25–50%

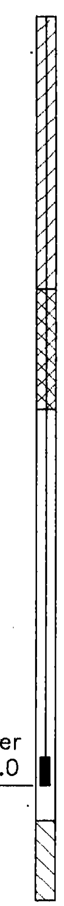
Rock core recovery 50–75%

Rock core recovery 75–90%

Rock core recovery 90– 100%

Elevation at bottom of exploration.

LEGEND FOR PIEZOMETER



Boring Number	Piezometer Number
NOT APPLICABLE	PZ-4
NOT APPLICABLE	PZ-8
NOT APPLICABLE	PZ-9
NOT APPLICABLE	PZ-11
FD-89-3	PZ-12A
FD-89-3	PZ-12B
FD-89-5	PZ-13A
FD-89-5	PZ-13B
FD-89-2	PZ-14A
FD-89-2	PZ-14B
FD-89-4	PZ-15A
FD-89-4	PZ-15B
FD-89-1	PZ-16A
FD-89-1	PZ-16B

HALEY & ALDRICH INC

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

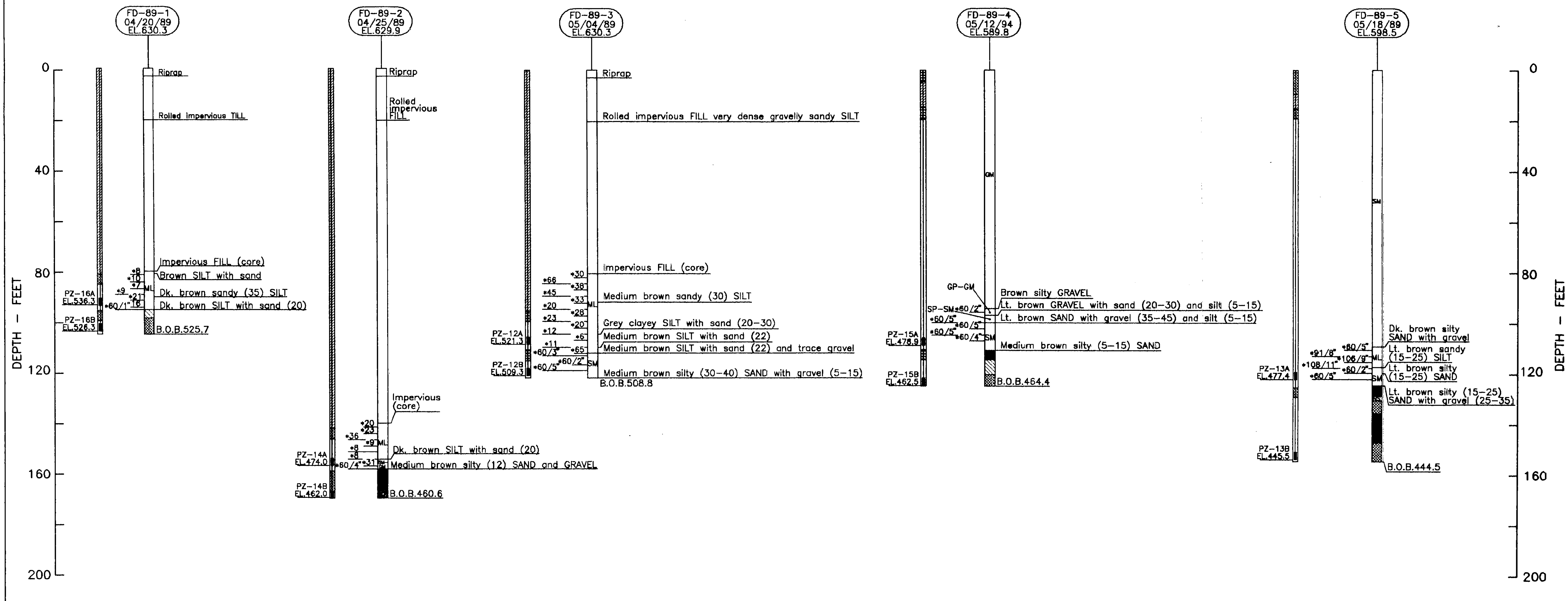
GENERAL LEGEND AND NOTES

SCALE: NONE

JULY 1995

11163-006 B62

FIGURE 6



NOTES:

1. TEST BORINGS AND PIEZOMETER LOGS PROVIDED BY THE U.S. ARMY CORPS OF ENGINEERS.

2. REFER TO FIGURE 6 FOR GENERAL LEGEND AND NOTES.

HALEY & ALDRICH INC.
Geotechnical Engineers & Environmental Consultants

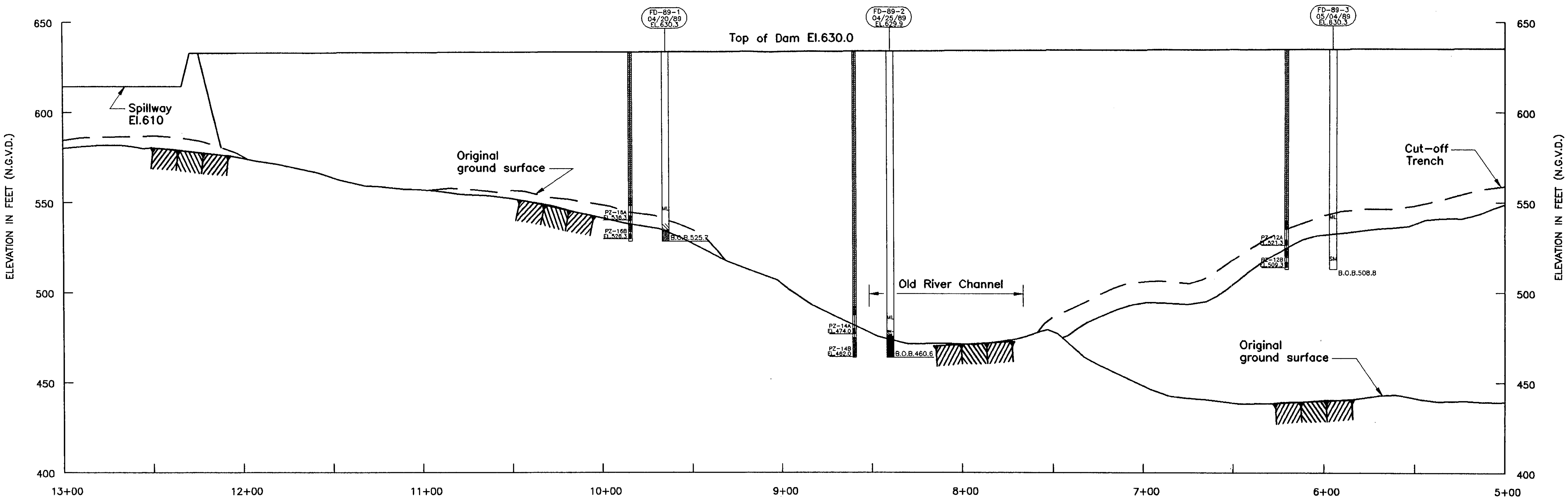
CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

ENGINEERING LOGS
PIEZOMETER EXPLORATIONS

SCALE: AS SHOWN | JULY 1995

11163-006 B64

FIGURE 7



ENGINEERING LOG PROFILE ALONG CENTERLINE OF DAM (LOOKING UPSTREAM)

NOTES:

1. CROSS SECTIONS PREPARED BY THE U.S. ARMY CORPS OF ENGINEERS AND PUBLISHED IN THE REPORT ENTITLED "PERIODIC INSPECTION REPORT NO.1, KNIGHVILLE DAM, CONNECTICUT RIVER BASIN, WESTFIELD RIVER, MASSACHUSETTS.
2. ALL ELEVATIONS CORRESPOND TO FEET N.G.V.D.
3. REFER TO FIGURE 6 FOR GENERAL LEGEND AND NOTES.
4. REFER TO FIGURE 7 FOR DESCRIPTION OF ENGINEERING LOGS.

0 60 120
SCALE IN FEET

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

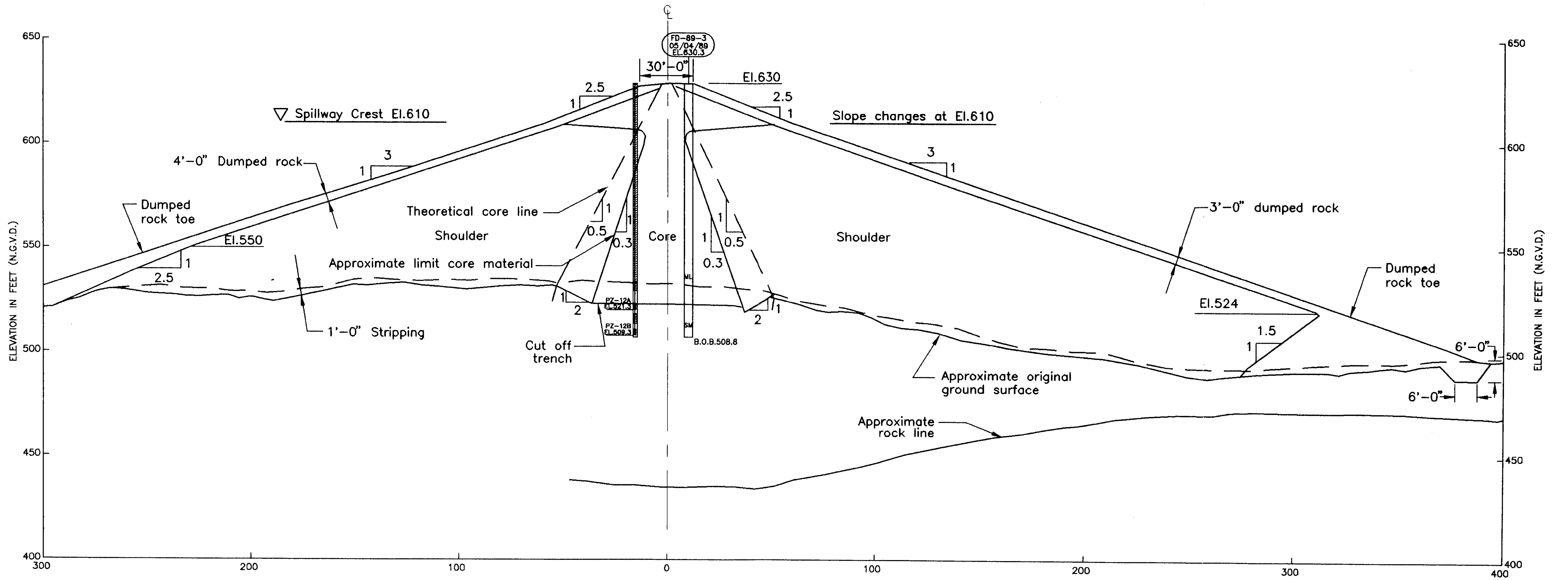
ENGINEERING LOG PROFILE
CENTERLINE OF DAM

SCALE: AS SHOWN

JULY 1995

FIGURE 8

11163-006 B65



ENGINEERING LOG SECTION – STA. 6+00

NOTES:

1. CROSS SECTIONS PREPARED BY THE U.S. ARMY CORPS OF ENGINEERS AND PUBLISHED IN THE REPORT ENTITLED "PERIODIC INSPECTION REPORT NO. 1, KNIGHTVILLE DAM, WESTFIELD RIVER BASIN, HUNTINGTON, MASSACHUSETTS."
2. ALL ELEVATIONS CORRESPOND TO FEET N.G.V.D.
3. REFER TO FIGURE 6 FOR GENERAL LEGEND AND NOTES.
4. REFER TO FIGURE 7 FOR FULL DESCRIPTION OF ENGINEERING LOGS.

0 50 100
SCALE IN FEET

HALEY & ALDRICH INC.
Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

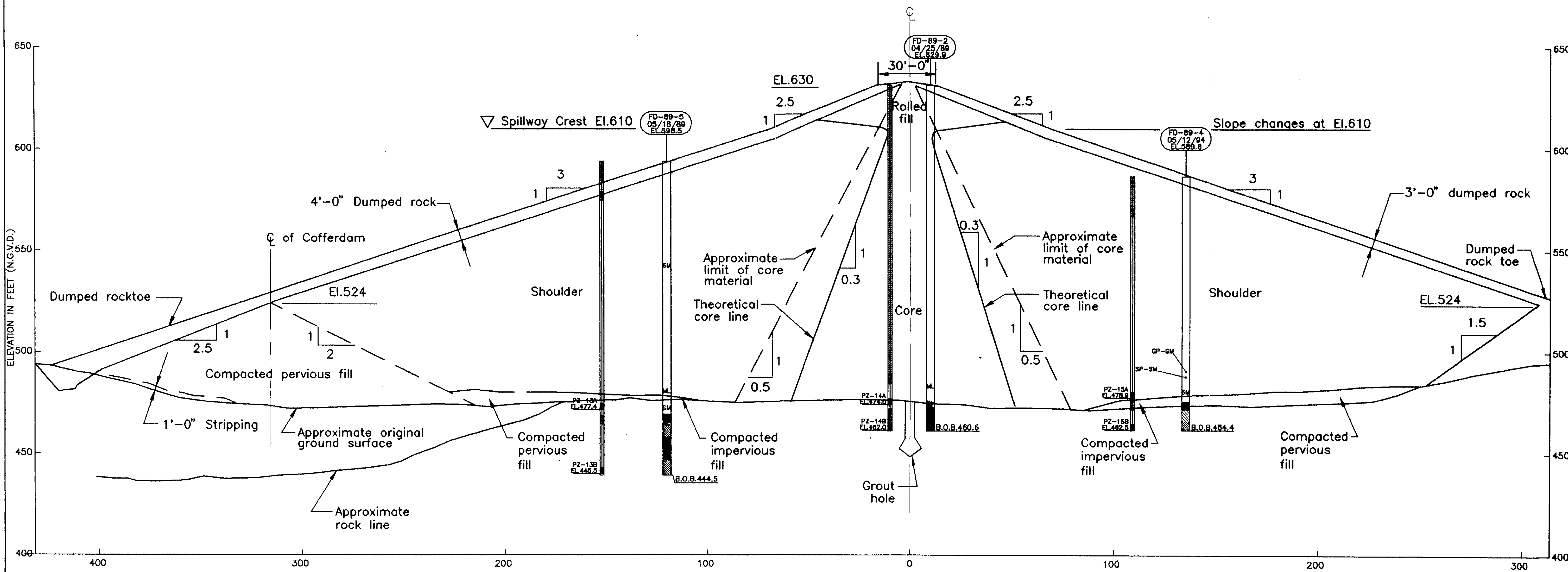
ENGINEERING LOG SECTION
STA. 6+00

SCALE: 1"=50'

JULY 1995

11163-006 B55

FIGURE 9



ENGINEERING LOG SECTION – STA. 8+75

NOTES:

1. CROSS SECTIONS PREPARED BY THE U.S. ARMY CORPS OF ENGINEERS AND PUBLISHED IN THE REPORT ENTITLED "PERIODIC INSPECTION REPORT NO. 1, KNIGHTVILLE DAM, WESTFIELD RIVER BASIN, HUNTINGTON, MASSACHUSETTS."
2. ALL ELEVATIONS CORRESPOND TO FEET N.G.V.D.
3. REFER TO FIGURE 6 FOR GENERAL LEGEND AND NOTES.
4. REFER TO FIGURE 7 FOR FULL DESCRIPTION OF ENGINEERING LOGS.

0 50 100
SCALE IN FEET

HALEY & ALDRICH INC
Geotechnical Engineers & Environmental Consultants

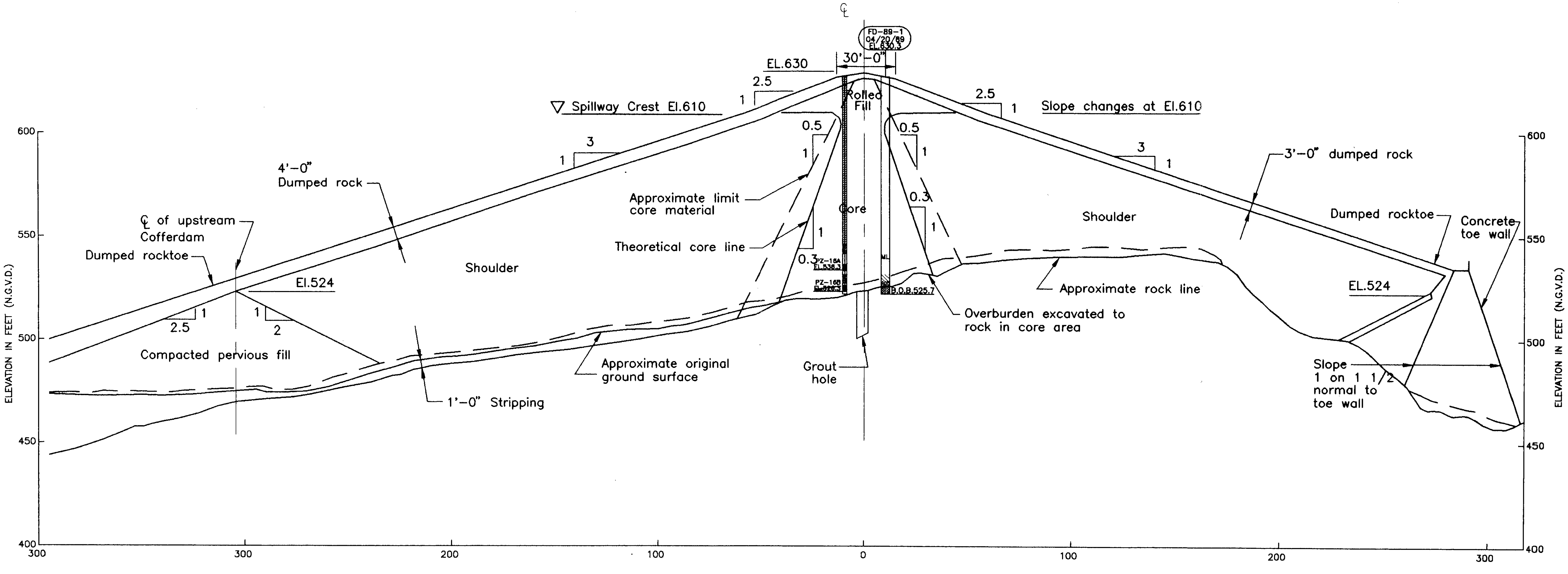
CONNECTICUT RIVER BASIN
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

ENGINEERING LOG SECTION
STA. 8+75

SCALE: 1"-50'
JULY 1995

11163-006 B56

FIGURE 10



ENGINEERING LOG SECTION – STA. 10+50

NOTES:

1. CROSS SECTIONS PREPARED BY THE U.S. ARMY CORPS OF ENGINEERS AND PUBLISHED IN THE REPORT ENTITLED "PERIODIC INSPECTION REPORT NO. 1, KNIGHTVILLE DAM, WESTFIELD RIVER BASIN, HUNTINGTON, MASSACHUSETTS."
2. ALL ELEVATIONS CORRESPOND TO FEET N.G.V.D.
3. REFER TO FIGURE 6 FOR GENERAL LEGEND AND NOTES.
4. REFER TO FIGURE 7 FOR FULL DESCRIPTION OF ENGINEERING LOGS.

0 50 100
SCALE IN FEET

HALEY & ALDRICH, INC.
Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

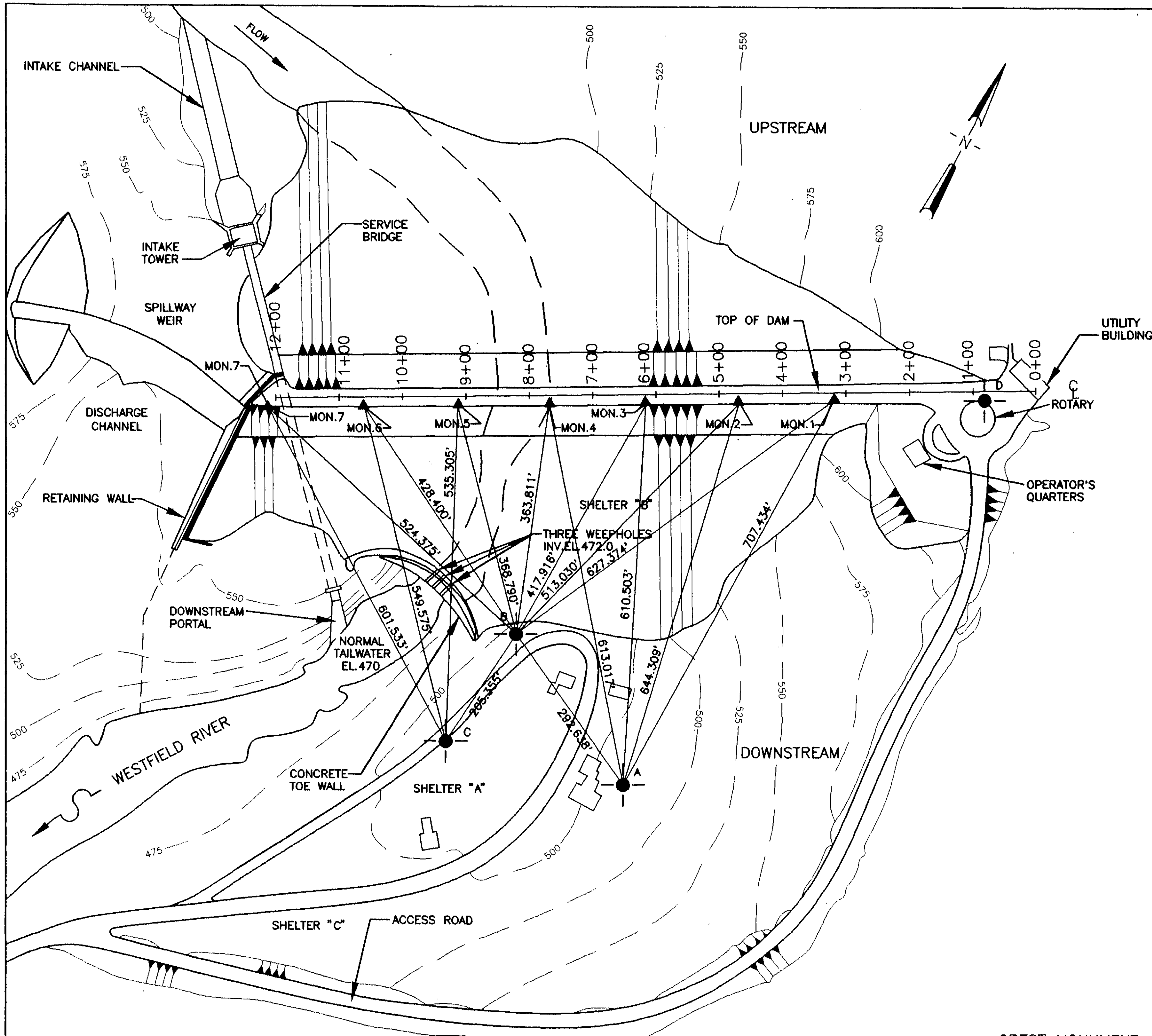
ENGINEERING LOG SECTION
STA. 10+50

SCALE: 1"–50'

JULY 1995

11163-006 B54

FIGURE 11



LEGEND:

A — CONTROL POINT FOR VERTICAL AND HORIZONTAL CONTROL

▲ — CREST MONUMENT 1991

NOTES:

1. MEASUREMENTS SHOWN ARE FROM FEBRUARY 1991 SURVEY. REFER TO SURVEY BOOK FC52 AND FC596 FOR DESCRIPTION AND LOCATION OF CONTROL POINTS. BOOKS ARE STORED IN NEDED DESIGN DIVISION. SURVEY BRANCH PLAN STORED IN NEDED DESIGN DIVISION, CIVIL LAYOUT BRANCH.

2. ALL ELEVATIONS SHOWN ON THIS SHEET ARE IN TERMS OF FEET N.G.V.D.

0 200 400
SCALE IN FEET

CREST MONUMENT
SETTLEMENT AND MOVEMENT RECORD

DATE	JUNE 1985			FEBRUARY 1991		
	NORTHING	EASTING	ELEVATION	NORTHING	EASTING	ELEVATION
MON 1	11686.422	4783.203	630.394	11686.3407	4783.2708	630.389
MON 2	11552.026	4721.892	629.986	11511.9749	4721.9095	629.971
MON 3	11414.311	4659.281	629.226	11414.2655	4659.3138	629.203
MON 4	11279.000	4597.593	628.812	11278.9923	4597.6518	628.774
MON 5	11143.665	4533.529	629.581	11143.7034	4533.5779	629.558
MON 6	11007.356	4470.732	629.966	11007.2483	4470.7787	629.967
MON 7	10872.427	4408.732	630.031	10872.3620	4408.5689	630.044

CONTROL POINTS
LOCATION AND ELEVATION RECORD

CONTROL POINT	NORTHING	EASTING	ELEVATION
A	11104.201	5185.212	NA
B	11068.928	4894.707	NA
C	10898.670	5009.524	NA
D	NA	NA	631.053

11163-006 B61

HALEY & ALDRICH INC

Geotechnical Engineers & Environmental Consultants

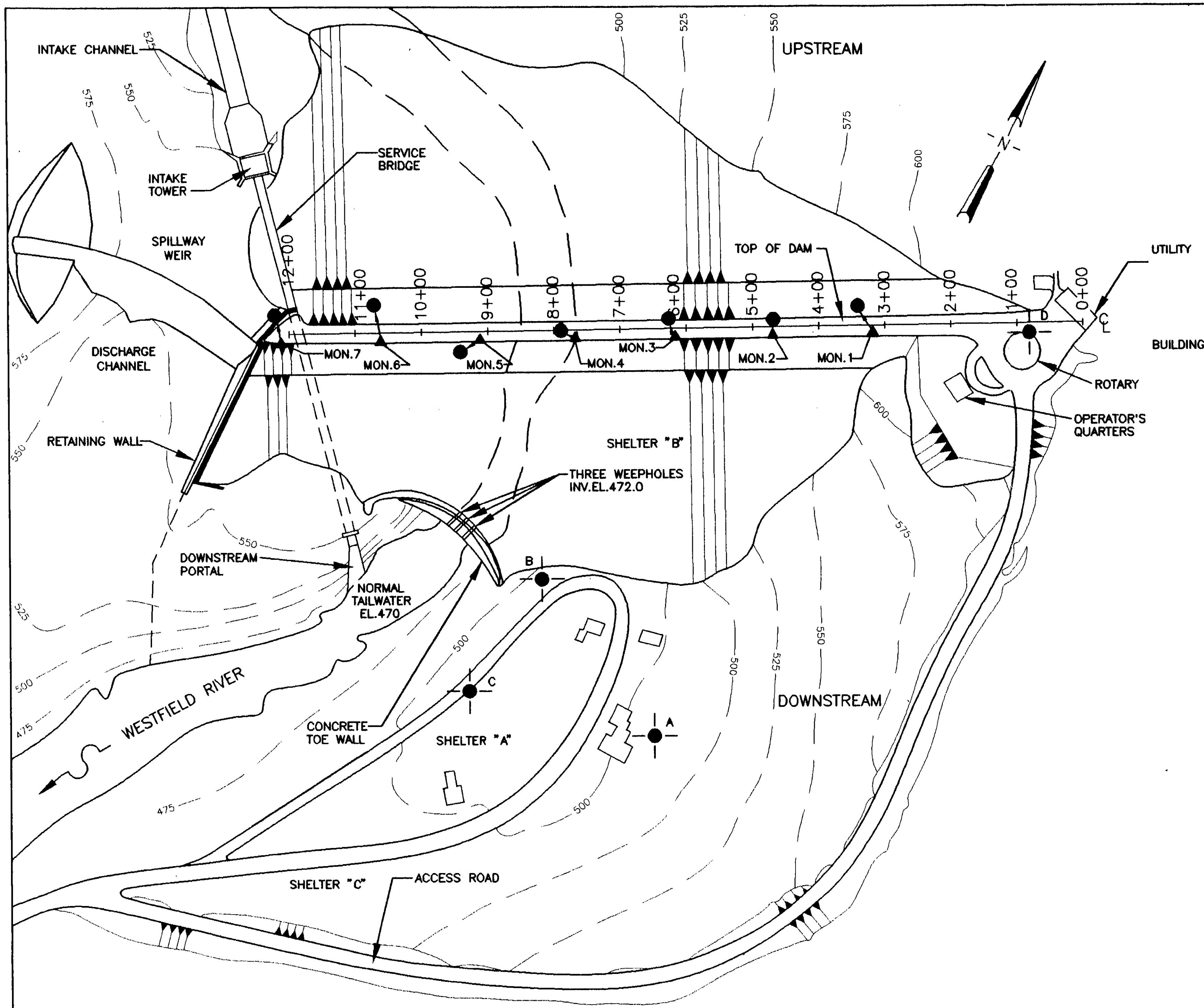
CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

GENERAL LAYOUT, LOCATION AND SURVEY

SCALE: 1" = 200'

JULY 1995

FIGURE 12



LEGEND:

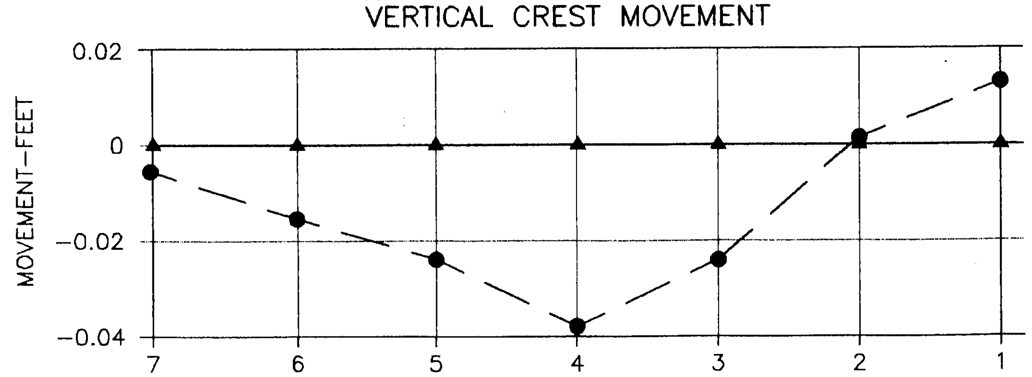
- □ CREST MONUMENT 1985
- △ CREST MONUMENT 1991
- DIRECTION OF HORIZONTAL MOVEMENT SCALE: 1 INCH = 0.2 FEET
- CONTROL POINT FOR VERTICAL AND/OR HORIZONTAL CONTROL

NOTES:

1. ALL ELEVATIONS SHOWN ON THIS SHEET ARE IN TERMS OF FEET NGVD OR REFERRED TO THE ELEVATIONS SHOWN FOR THE TOP (CREST) OF DAM (ALSO GIVEN IN FEET N.G.V.D.).

0 200 400
SCALE IN FEET

ELEVATION
VERTICAL CREST MOVEMENT



LEGEND:

- ELEVATION AS OF JUNE 1985
- ELEVATION AS OF FEBRUARY 1991

HALEY & ALDRICH INC

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

HORIZONTAL AND VERICAL MOVEMENT

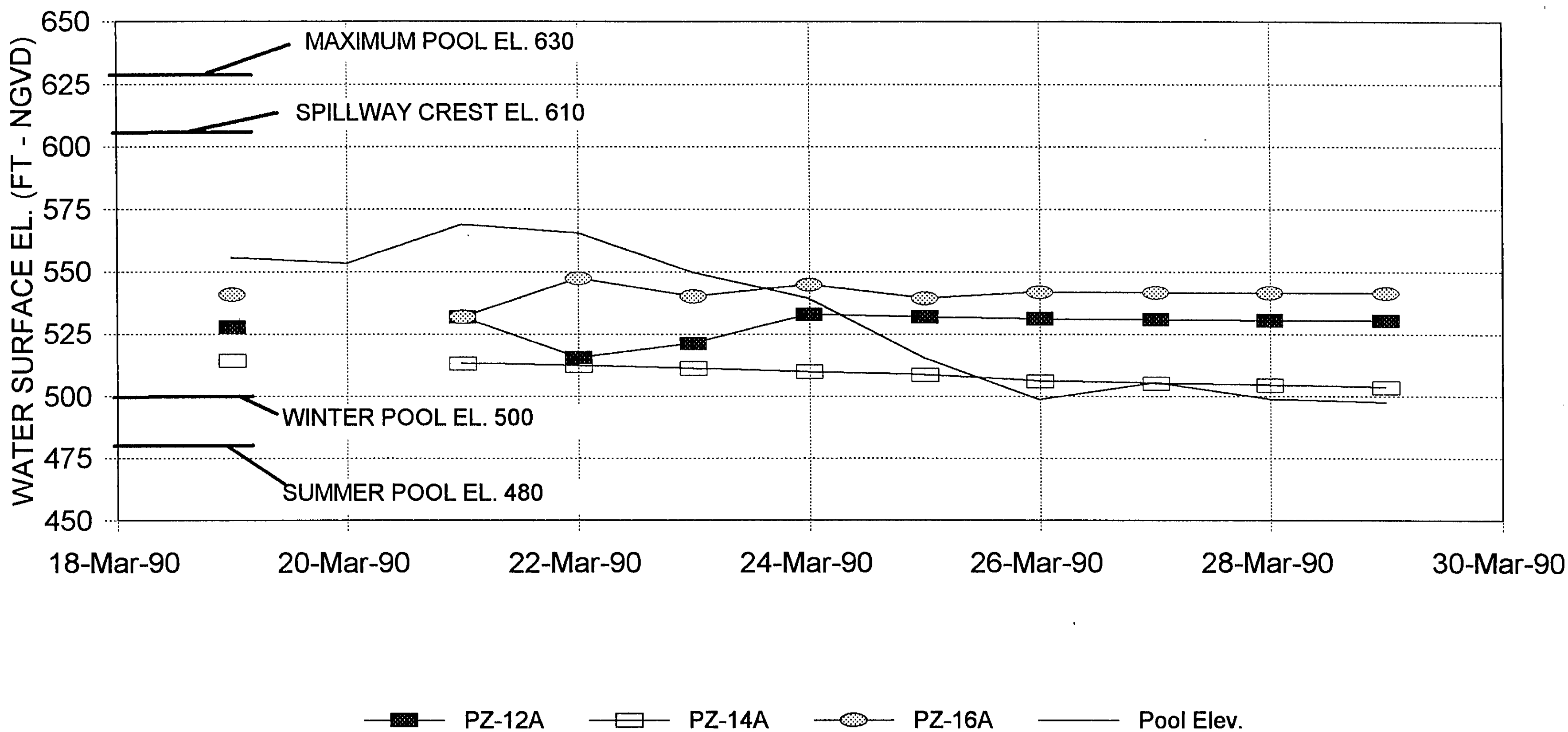
SCALE: 1" = 200'

JULY 1995

FIGURE 13

11163-006 B63

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-12A	521.3	630.3
PZ-14A	474.0	629.9
PZ-16A	536.3	630.3

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

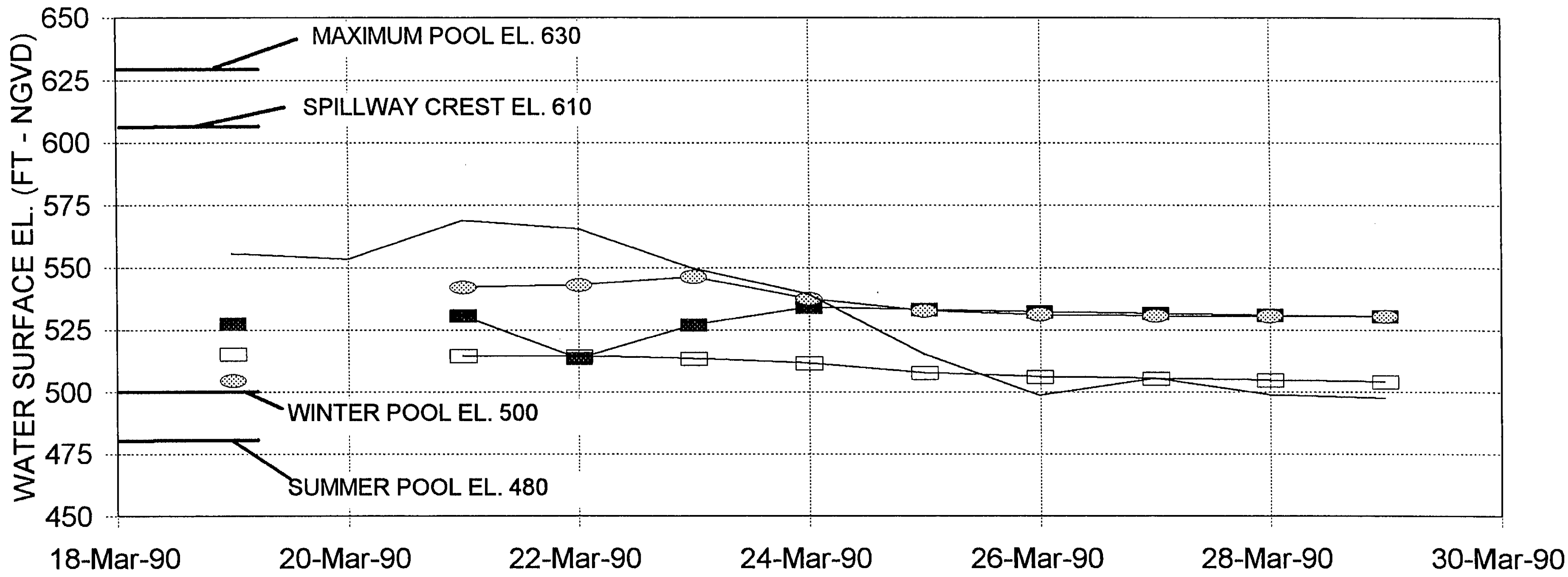
PIEZOMETER DATA TIME HISTORY PLOTS
CENTERLINE OF DAM
PZ-12A, PZ-14A, PZ-16A

SCALE: AS SHOWN

JULY 1995

FIGURE 14

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-12B	509.3	630.3
PZ-14B	462.0	629.9
PZ-16B	526.3	630.3

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

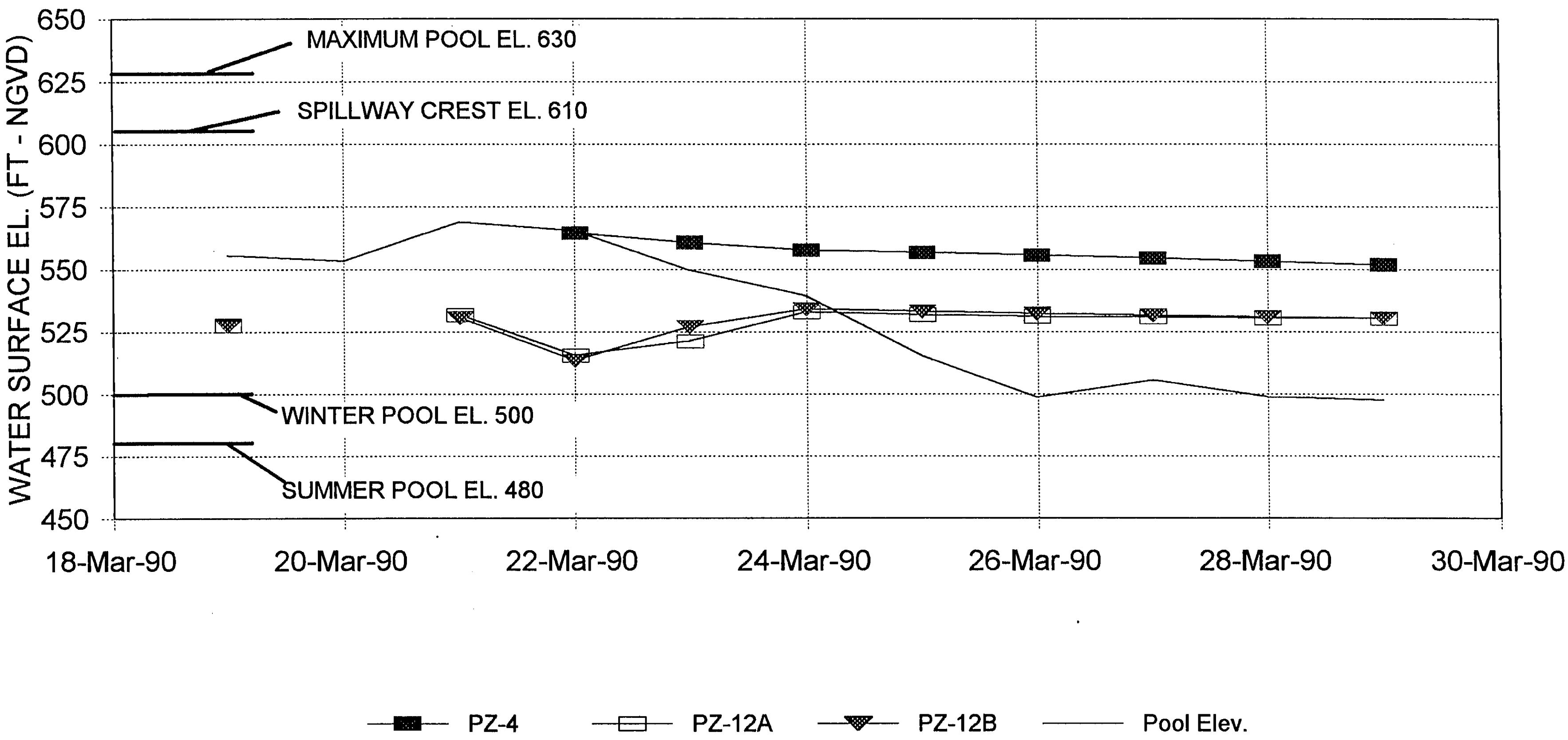
PIEZOMETER DATA TIME HISTORY PLOTS
CENTERLINE OF DAM
PZ-12B, PZ-14B, PZ-16B

SCALE: AS SHOWN

JULY 1995

FIGURE 15

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-4	531.0	569.3
PZ-12A	521.3	630.3
PZ-12B	509.3	630.3

HALEY & ALDRICH INC.
Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

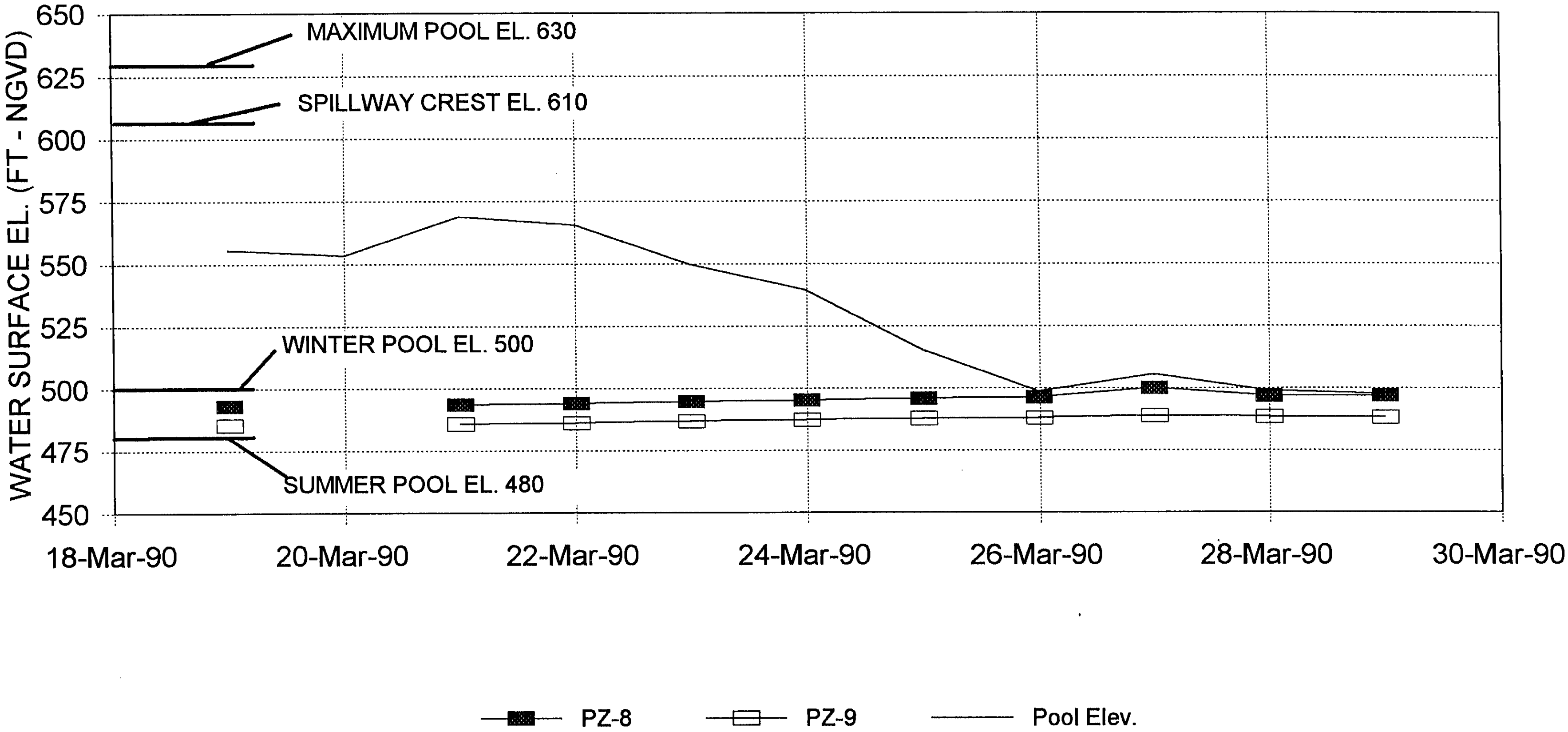
PIEZOMETER DATA TIME HISTORY PLOTS
STATION 6+00
PZ-4, PZ-12A, PZ-12B

SCALE: AS SHOWN

JULY 1995

FIGURE 16

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-8	473.6	604.7
PZ-9	475.4	568.8

HALEY & ALDRICH INC.
Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

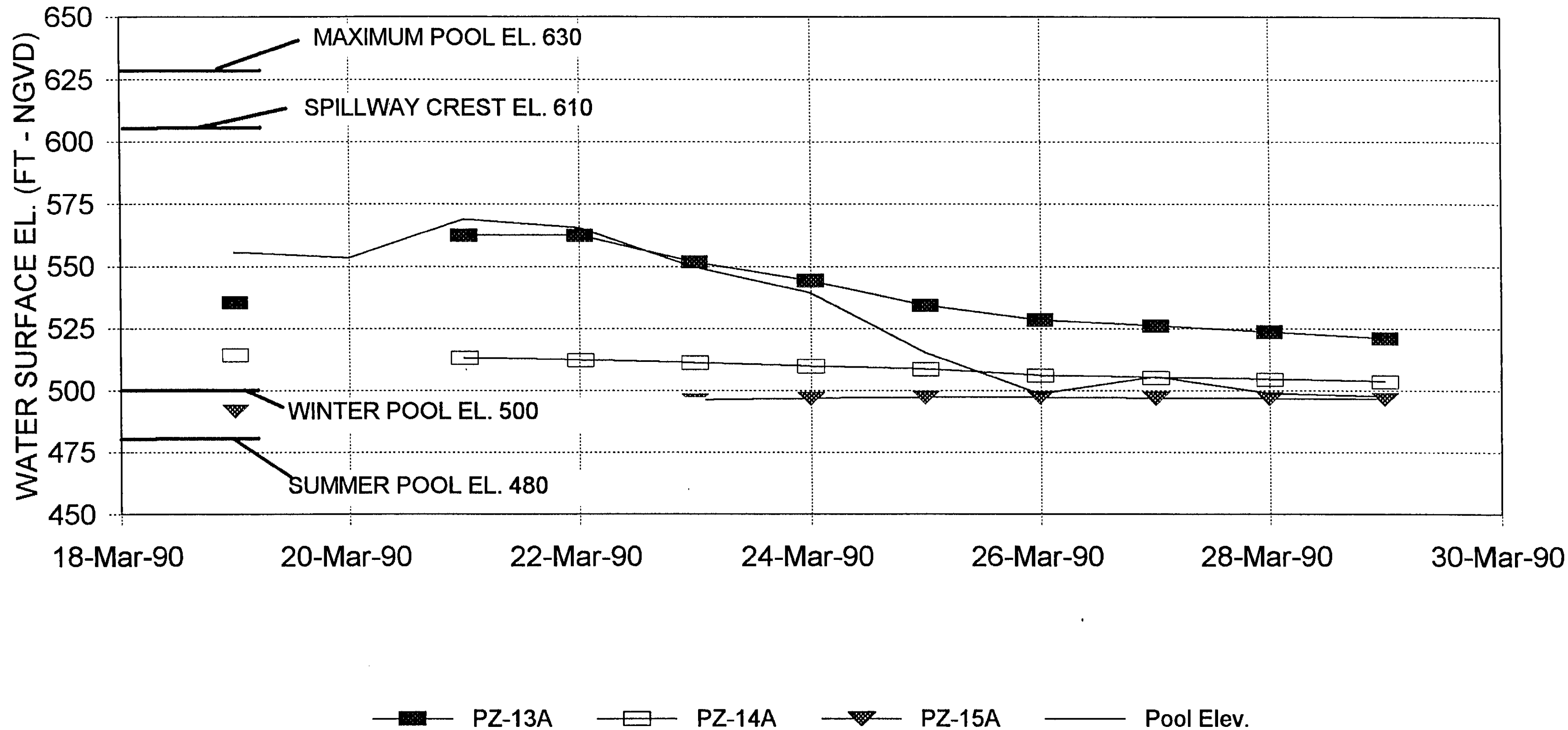
PIEZOMETER DATA TIME HISTORY PLOTS
STATION 8+75
PZ-8, PZ-9

SCALE: AS SHOWN

JULY 1995

FIGURE 17

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-13A	477.4	598.5
PZ-14A	474.0	629.9
PZ-15A	478.9	589.8

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

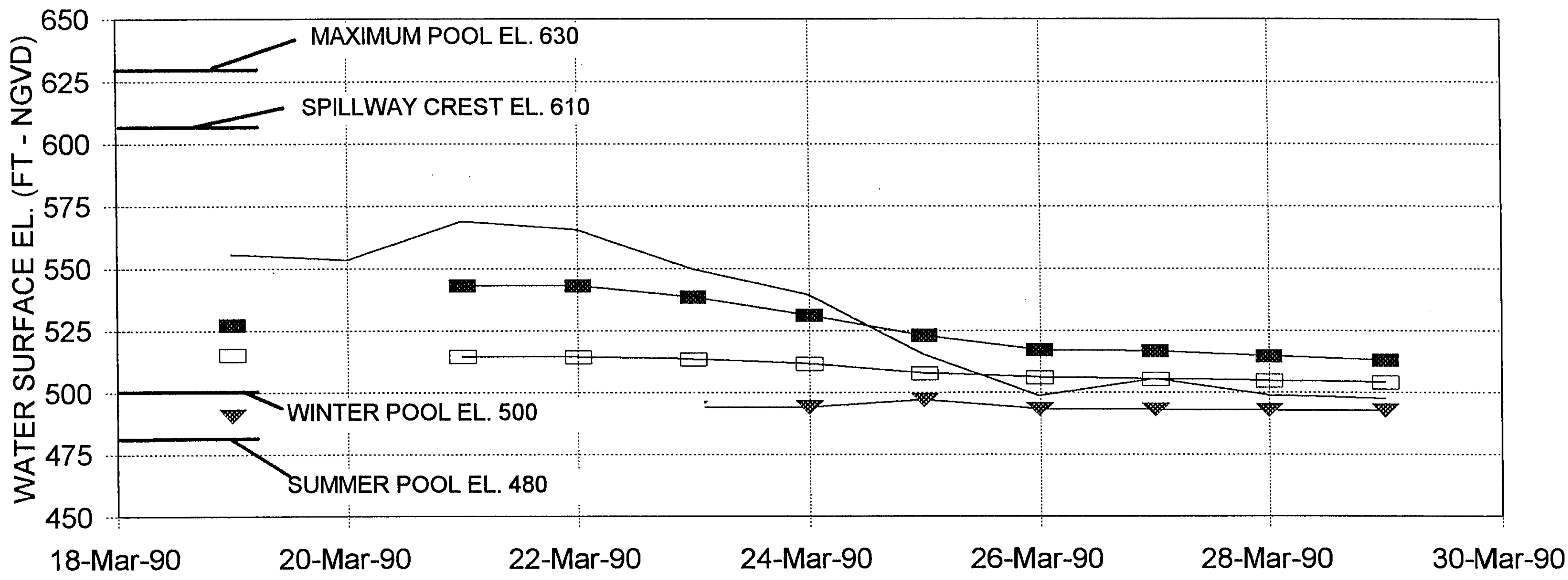
PIEZOMETER DATA TIME HISTORY PLOTS
STATION 8+75
PZ-13A, PZ-14A, PZ-15A

SCALE: AS SHOWN

JULY 1995

FIGURE 18

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-13B	445.5	598.5
PZ-14B	462.0	629.9
PZ-15B	462.5	589.8

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

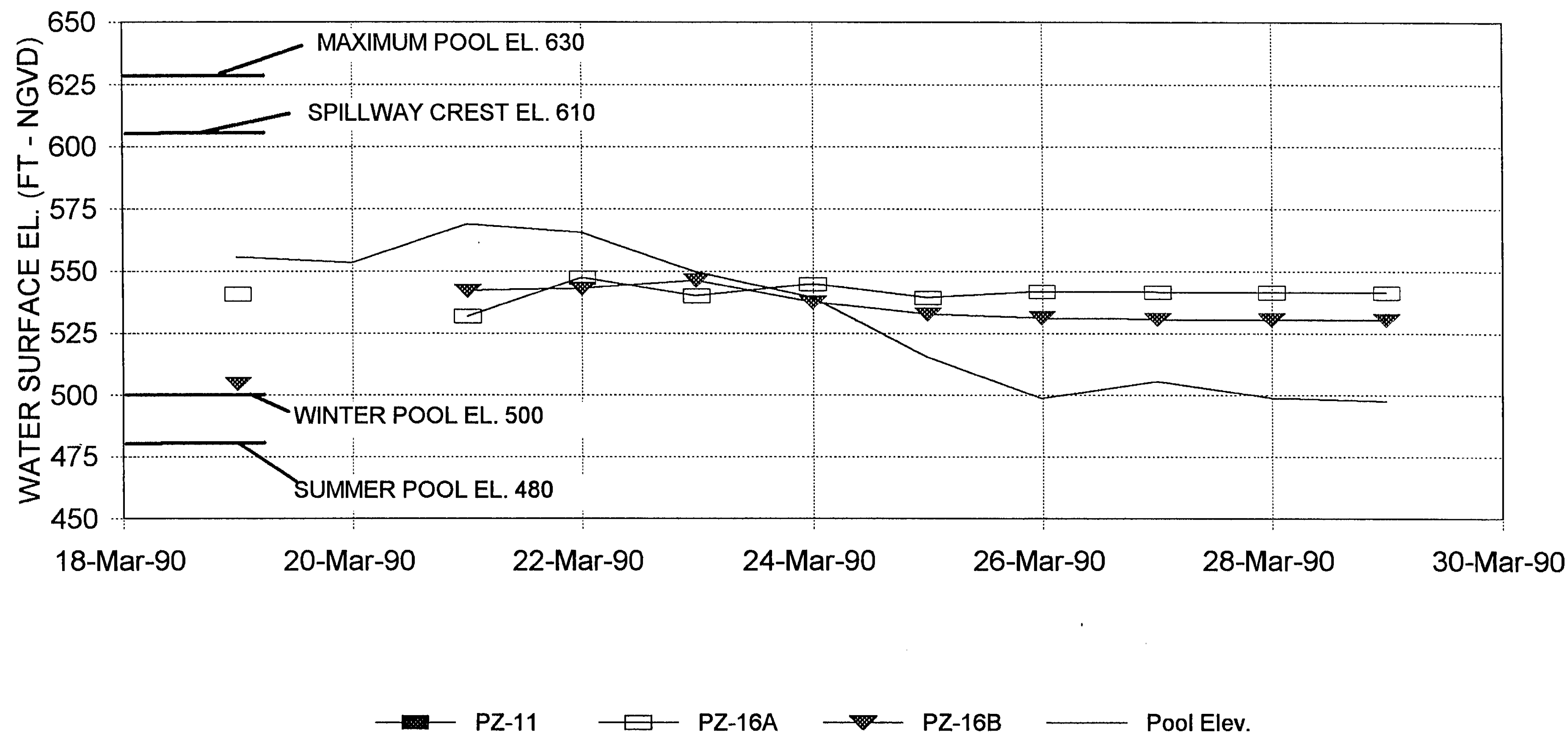
PIEZOMETER DATA TIME HISTORY PLOTS
STATION 8+75
PZ-13B, PZ-14B, PZ-15B

SCALE: AS SHOWN

JULY 1995

FIGURE 19

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-11	549.2	603.2
PZ-16A	536.3	630.3
PZ-16B	526.3	630.3

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

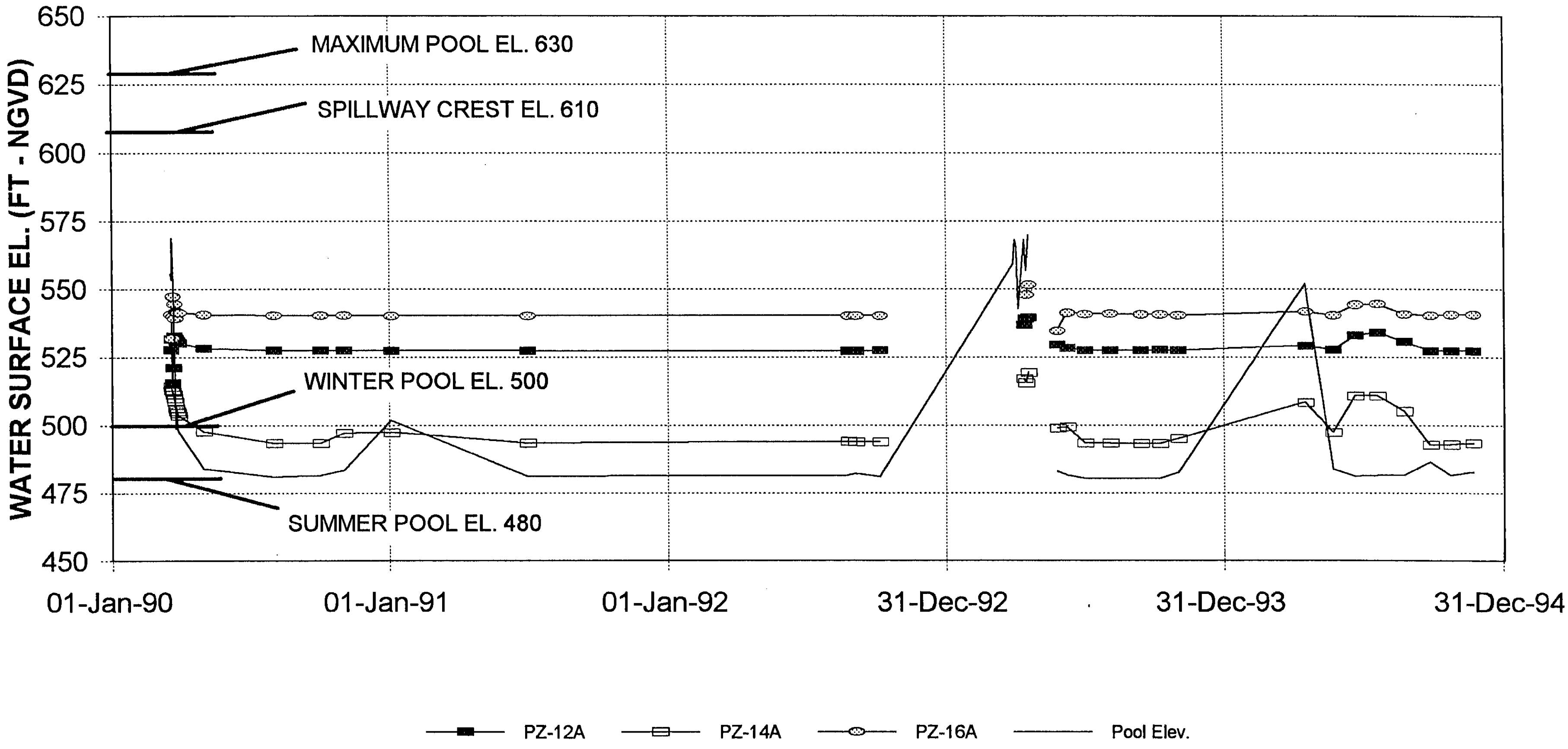
PIEZOMETER DATA TIME HISTORY PLOTS
STATION 10+50
PZ-11, PZ-16A, PZ-16B

SCALE: AS SHOWN

JULY 1995

FIGURE 20

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-12A	521.3	630.3
PZ-14A	474.0	629.9
PZ-16A	536.3	630.3

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

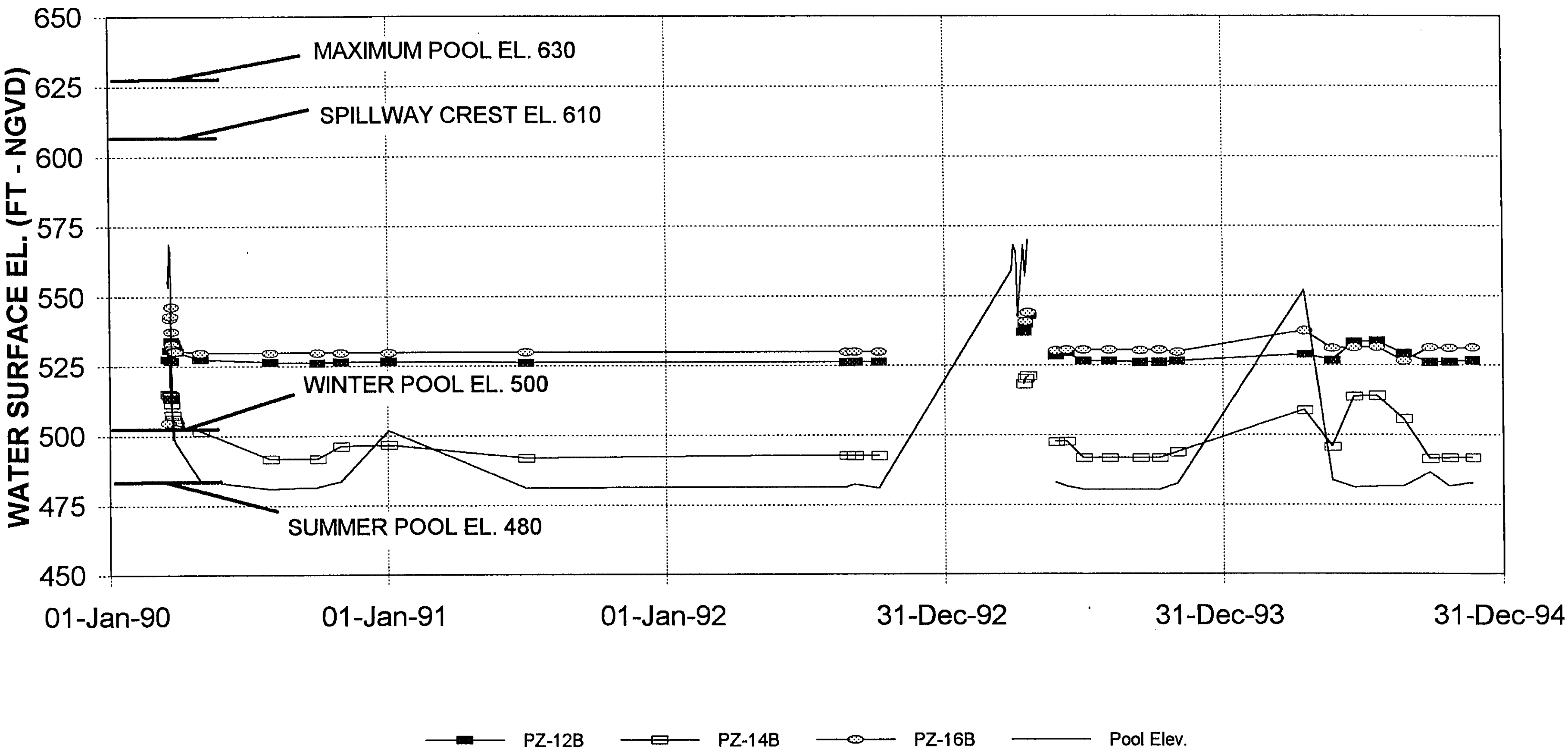
MARCH 1990 EVENT
CENTERLINE OF DAM
PZ-12A, PZ-14A, PZ-16A

SCALE: AS SHOWN

JULY 1995

FIGURE 21

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-12B	509.3	630.3
PZ-14B	462.0	629.9
PZ-16B	526.3	630.3

HALEY & ALDRICH INC.
Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

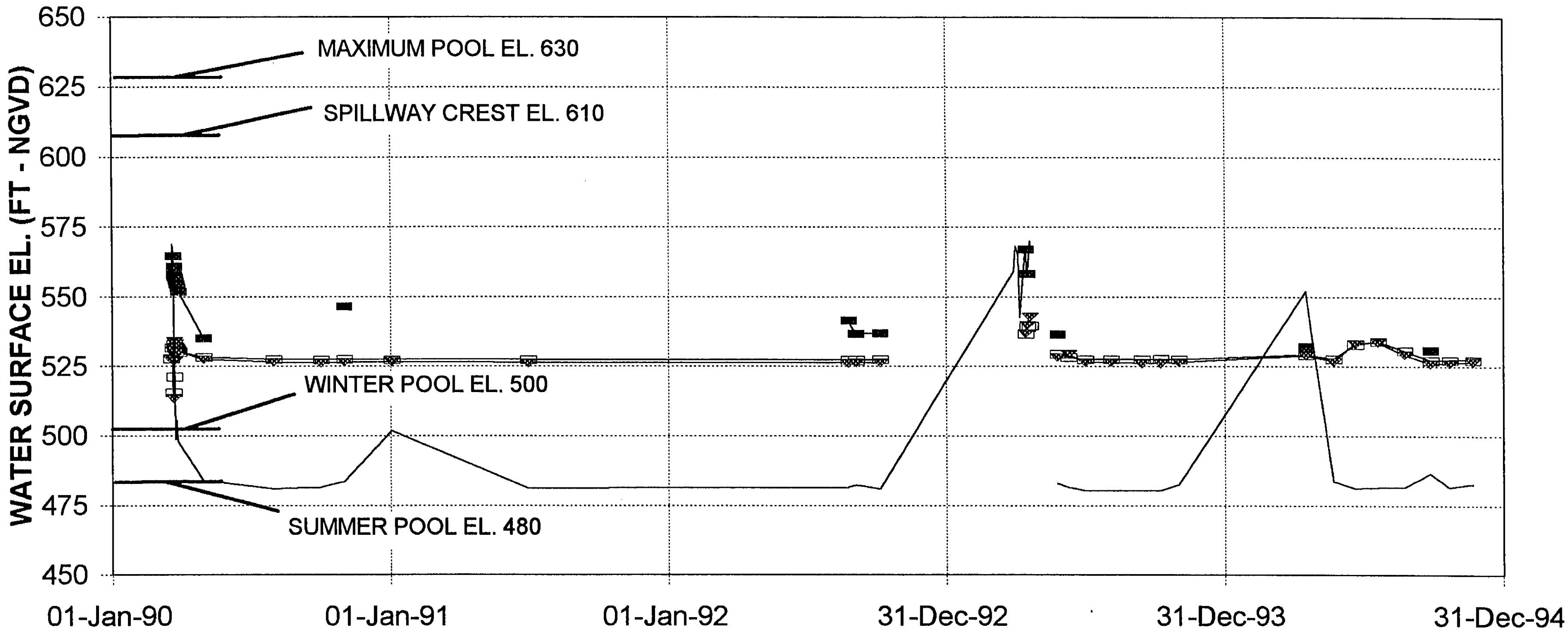
MARCH 1990 EVENT
CENTERLINE OF DAM
PZ-12B, PZ-14B, PZ-16B

SCALE: AS SHOWN

JULY 1995

FIGURE 22

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-4	531.0	569.3
PZ-12A	521.3	630.3
PZ-12B	509.3	630.3

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

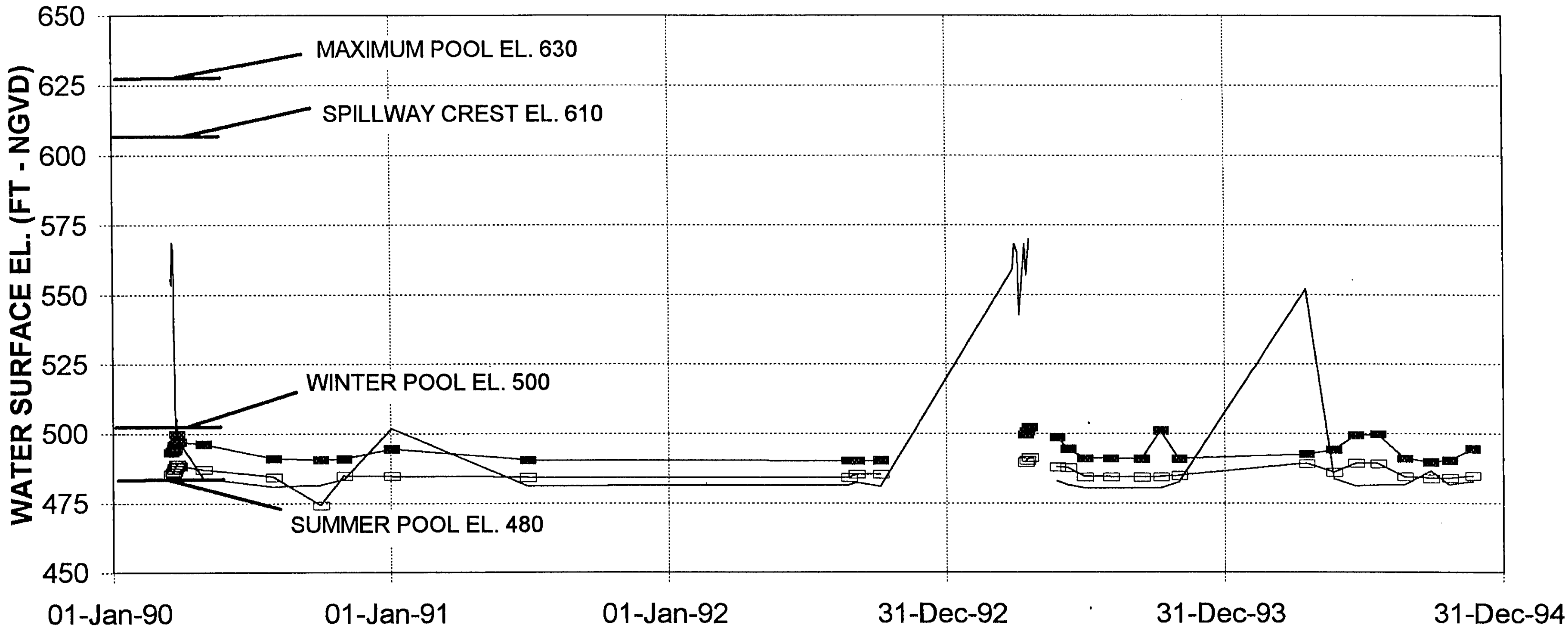
MARCH 1990 EVENT
STATION 6+00
PZ-4, PZ-12A, PZ-12B

SCALE: AS SHOWN

JULY 1995

FIGURE 23

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-8	473.6	604.7
PZ-9	475.4	568.8

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

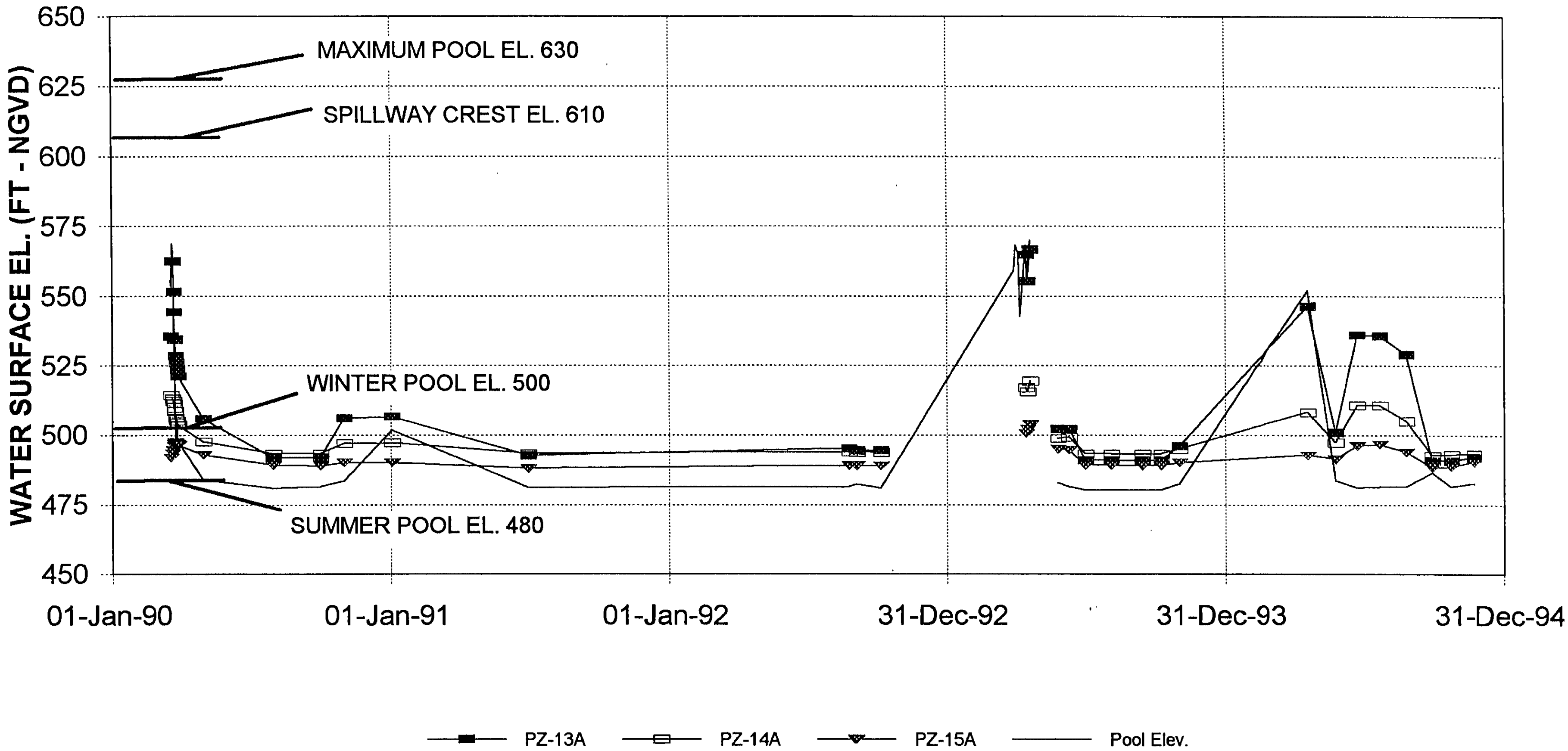
MARCH 1990 EVENT
STATION 8+75
PZ-8, PZ-9

SCALE: AS SHOWN

JULY 1995

FIGURE 24

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-13A	477.4	598.5
PZ-14A	474.0	629.9
PZ-15A	478.9	589.8

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

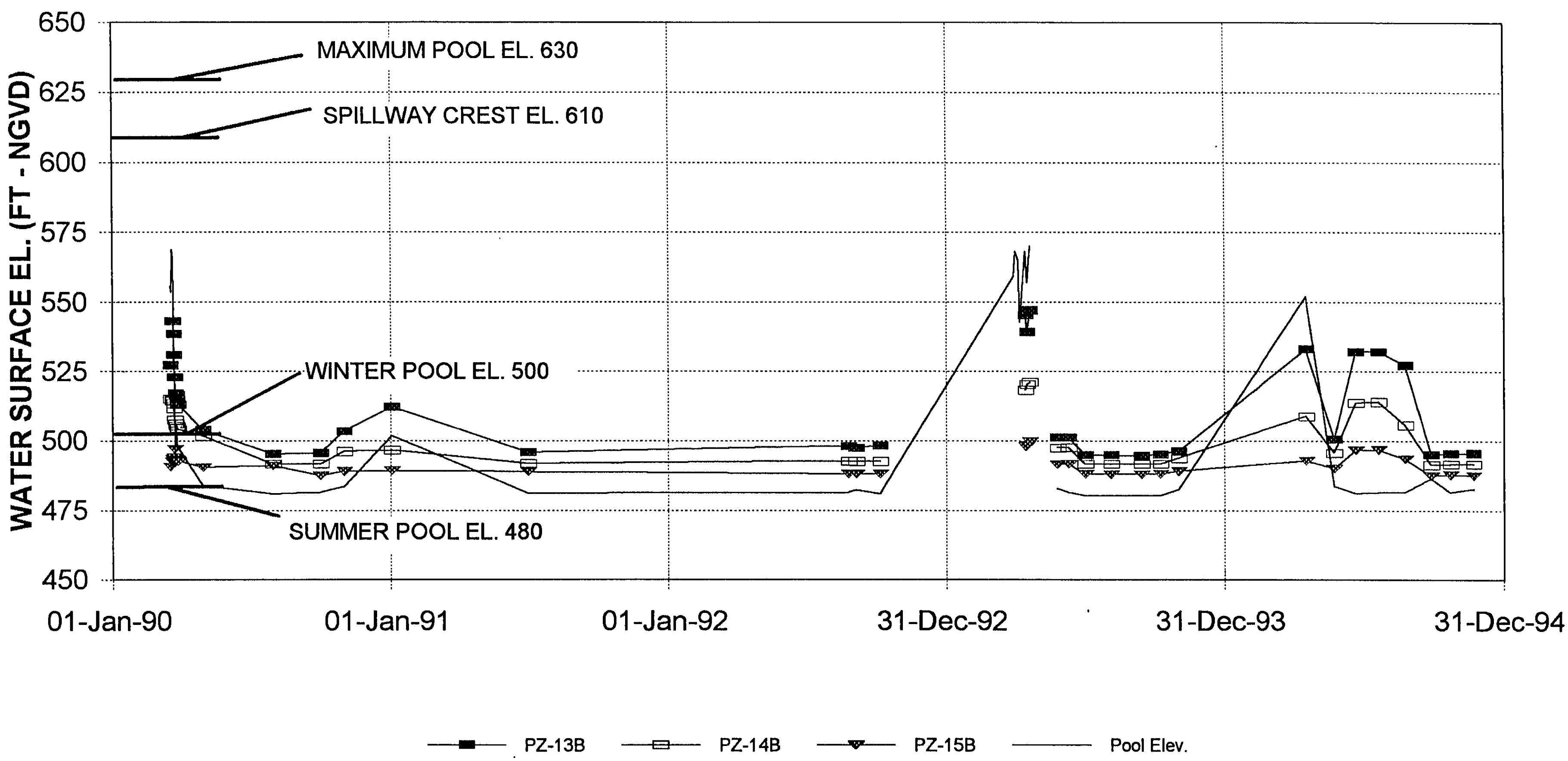
MARCH 1990 EVENT
STATION 8+75
PZ-13A, PZ-14A, PZ-15A

SCALE: AS SHOWN

JULY 1995

FIGURE 25

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-13B	445.5	598.5
PZ-14B	462.0	629.9
PZ-15B	462.5	589.8

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

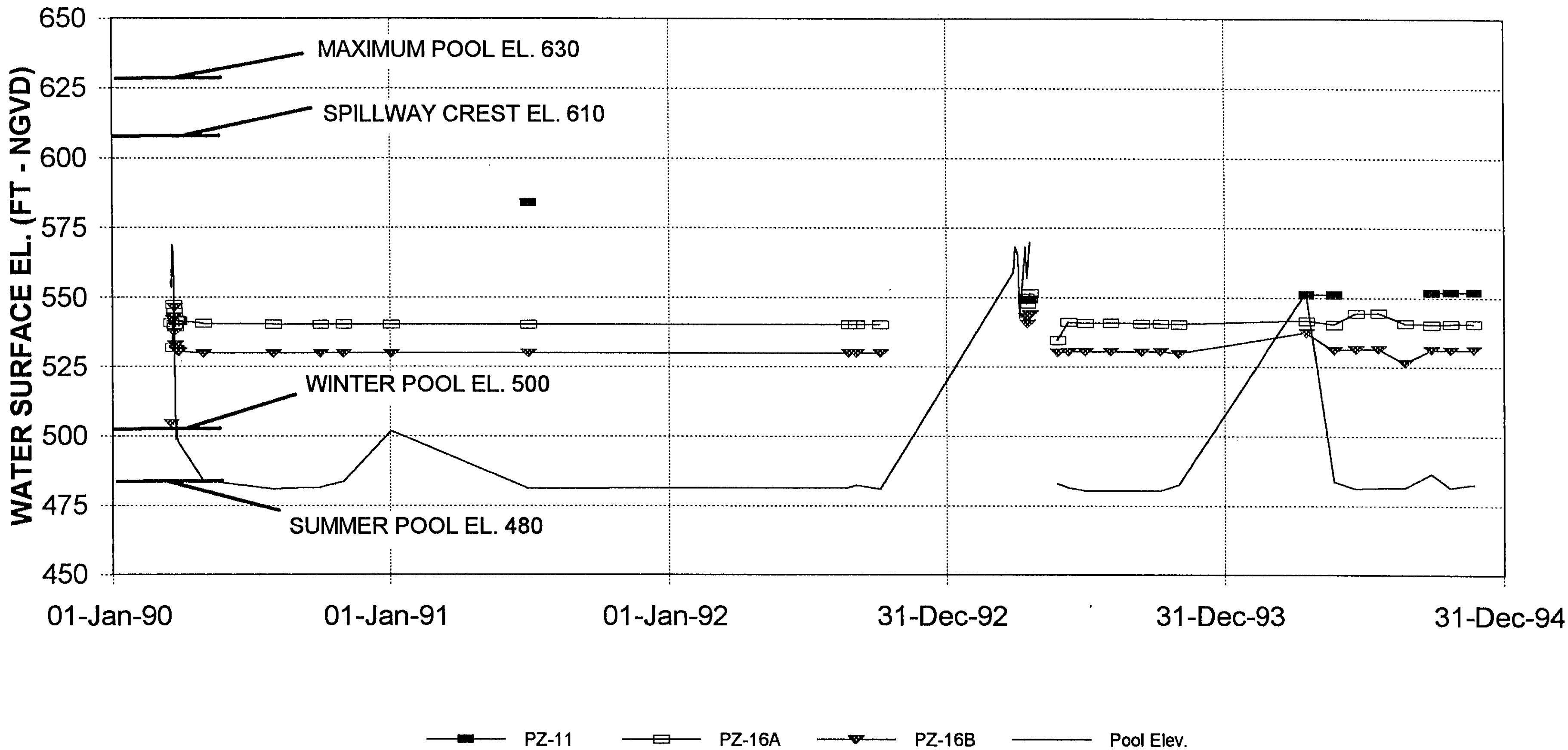
MARCH 1990 EVENT
STATION 8+75
PZ-13B, PZ-14B, PZ-15B

SCALE: AS SHOWN

JULY 1995

FIGURE 26

11163-006



Piezometer No.	Tip Elevation (ft. - NGVD)	Riser Pipe Elevation (ft. - NGVD)
PZ-11	549.2	603.2
PZ-16A	536.3	630.3
PZ-16B	526.3	630.3

HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

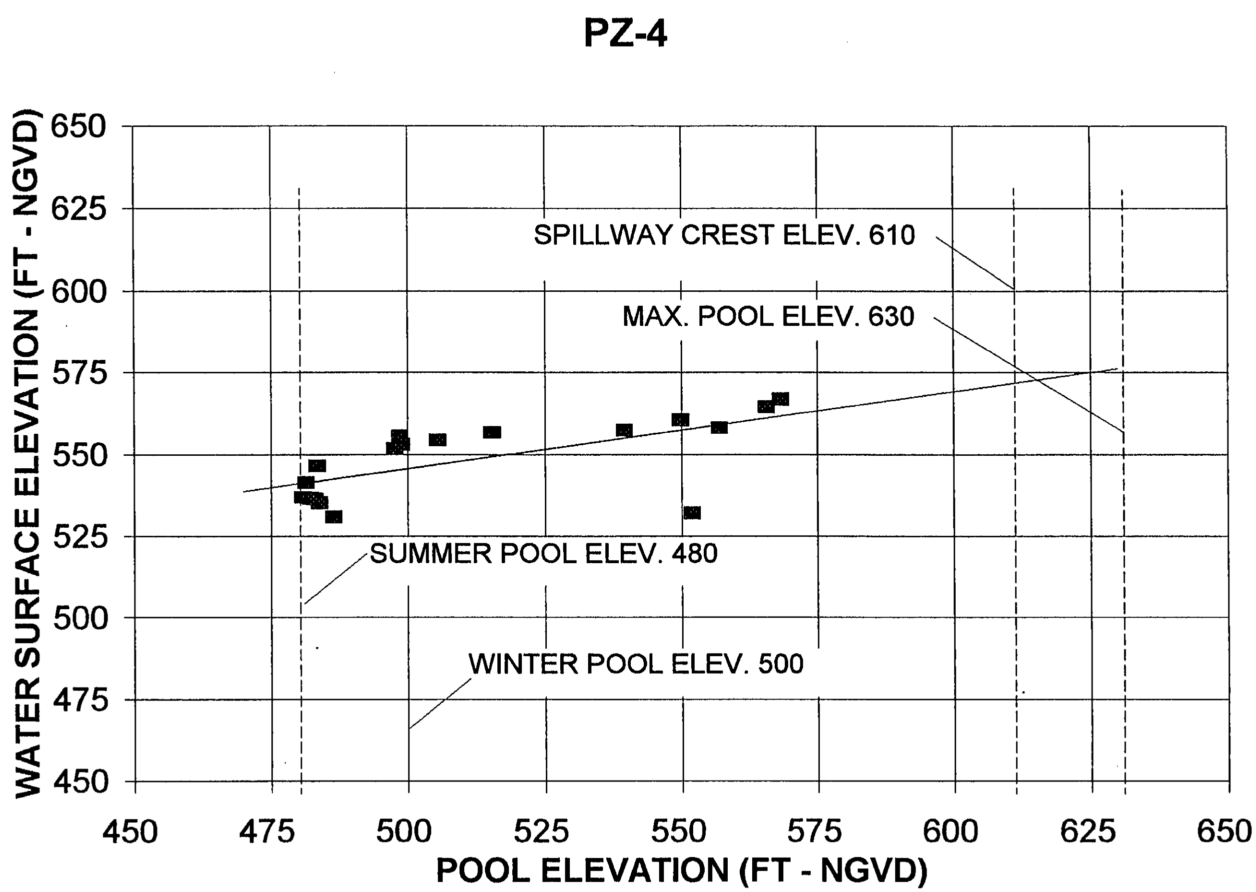
MARCH 1990 EVENT
STATION 10+50
PZ-11, PZ-16A, PZ-16B

SCALE: AS SHOWN

JULY 1995

FIGURE 27

FILE NO. 11163-006



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-4

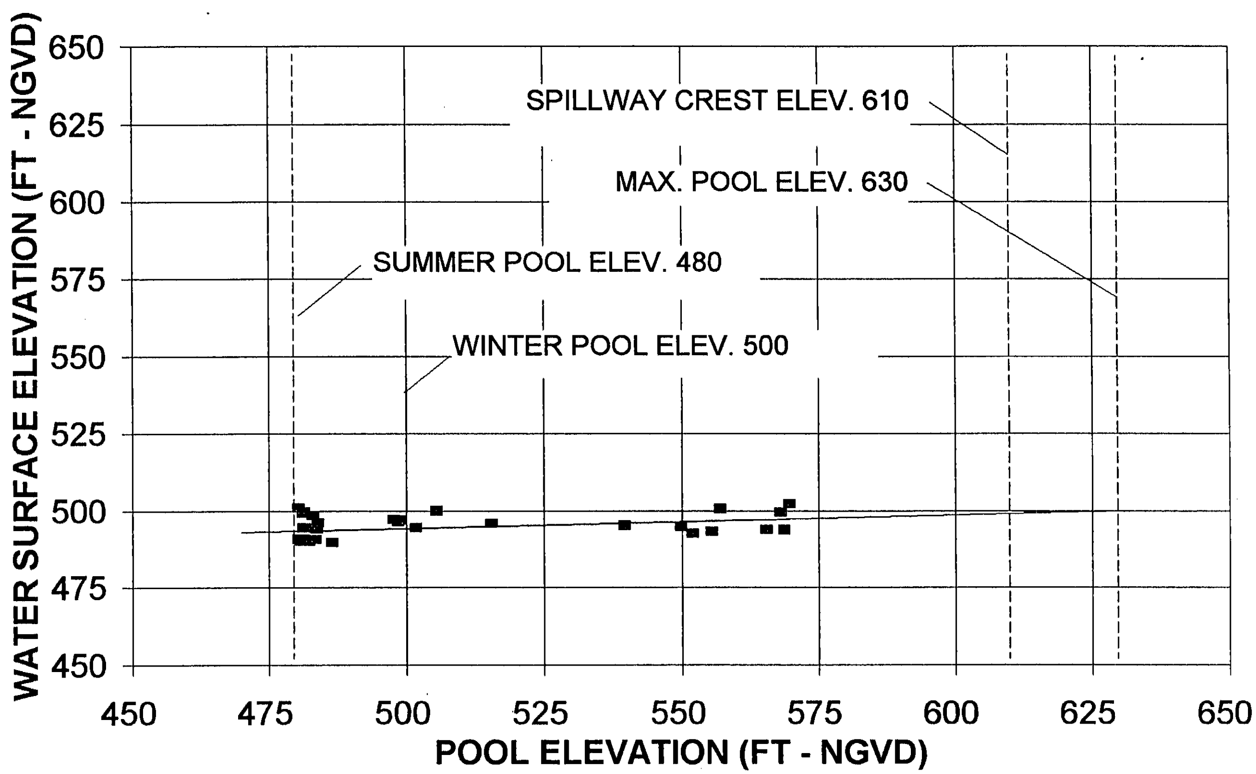
SCALE: AS SHOWN

JULY 1995

FIGURE 28

FILE NO. 11163-006

PZ-8



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-8

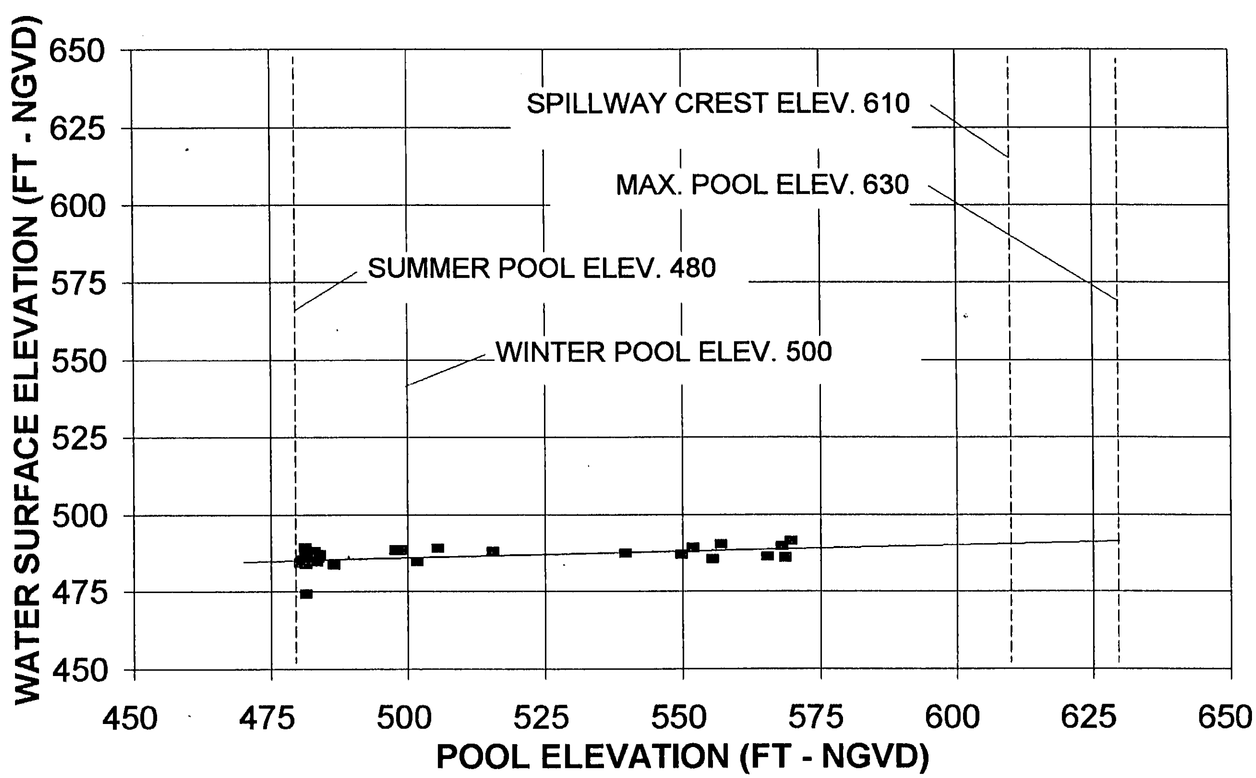
SCALE: AS SHOWN

JULY 1995

FIGURE 29

FILE NO. 11163-006

PZ-9



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION
vs. POOL ELEVATION
PZ-9

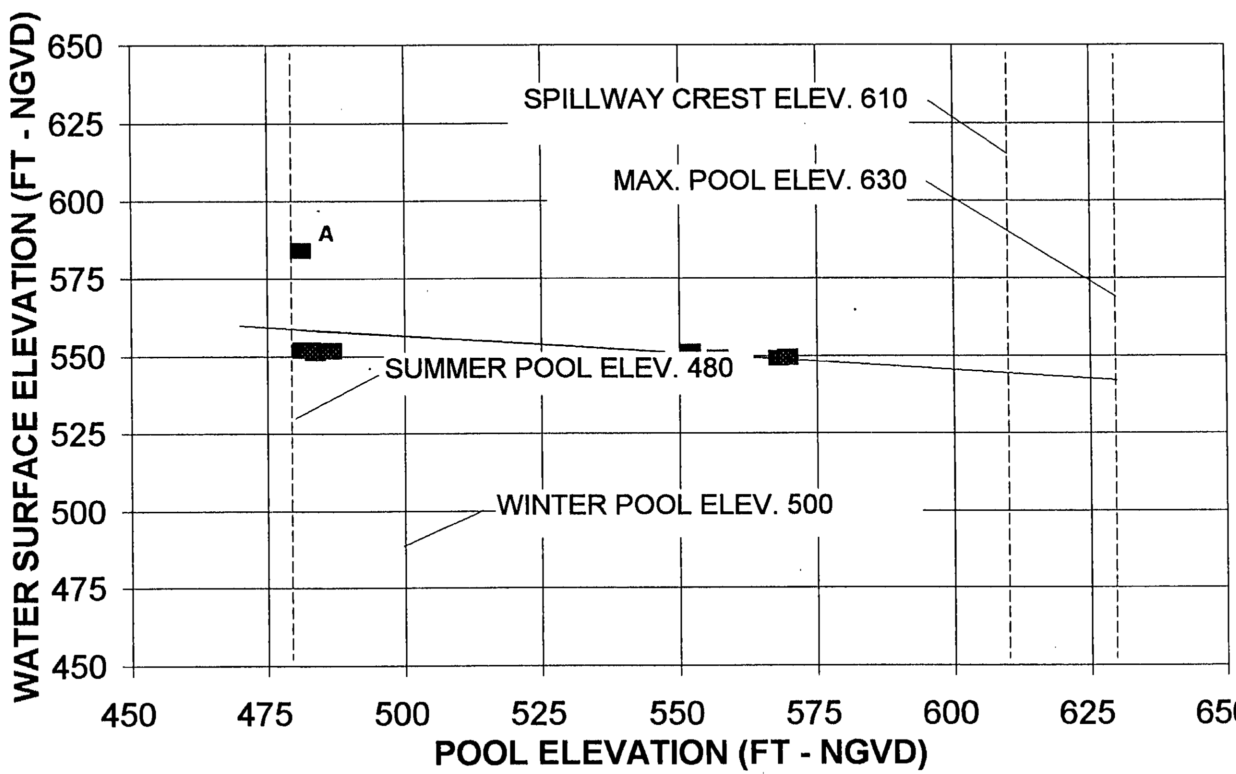
SCALE: AS SHOWN

JULY 1995

FIGURE 30

FILE NO. 11163-006

PZ-11



HALEY & ALDRICH INC.
Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

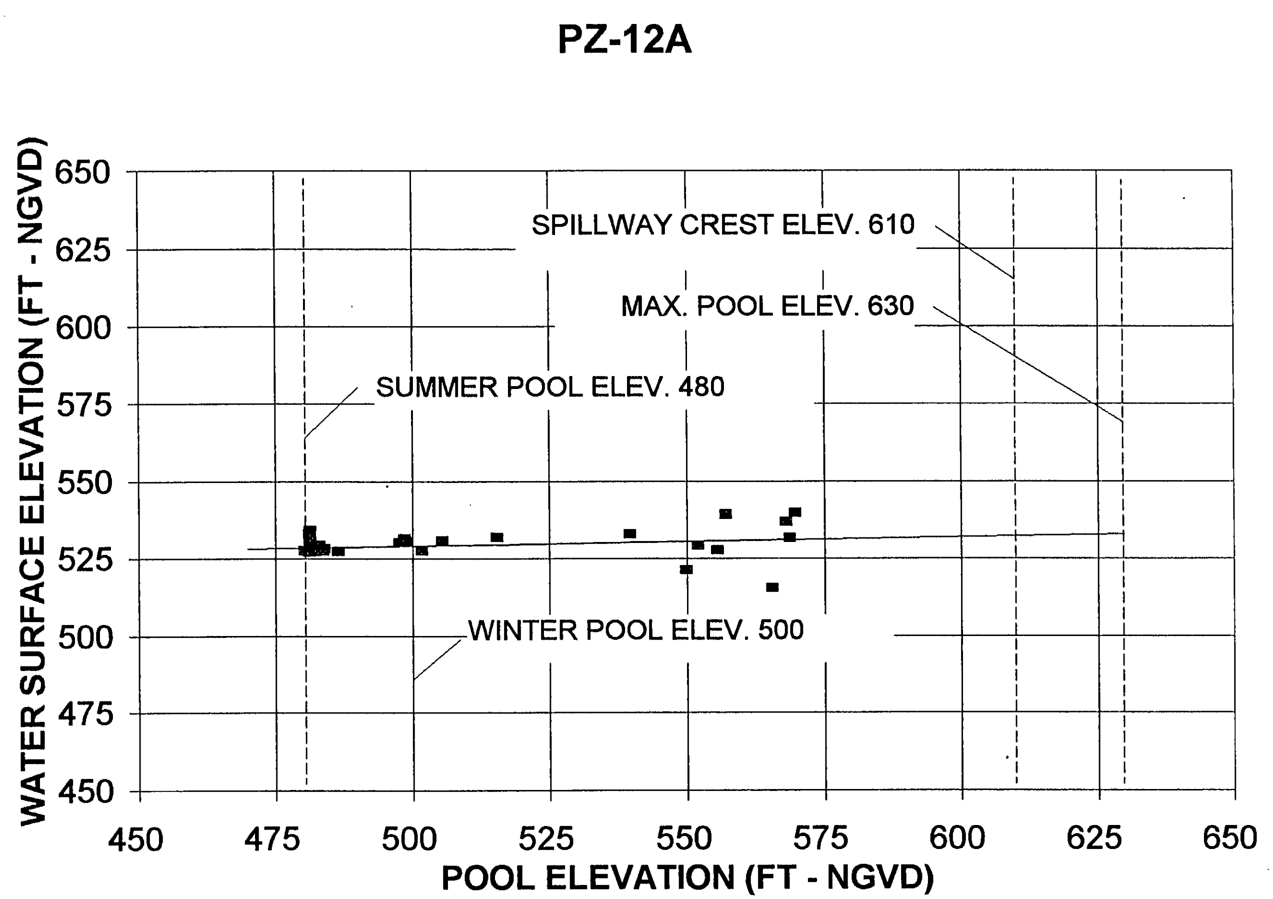
PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-11

SCALE: AS SHOWN

JULY 1995

FIGURE 31

FILE NO. 11163-006



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-12A

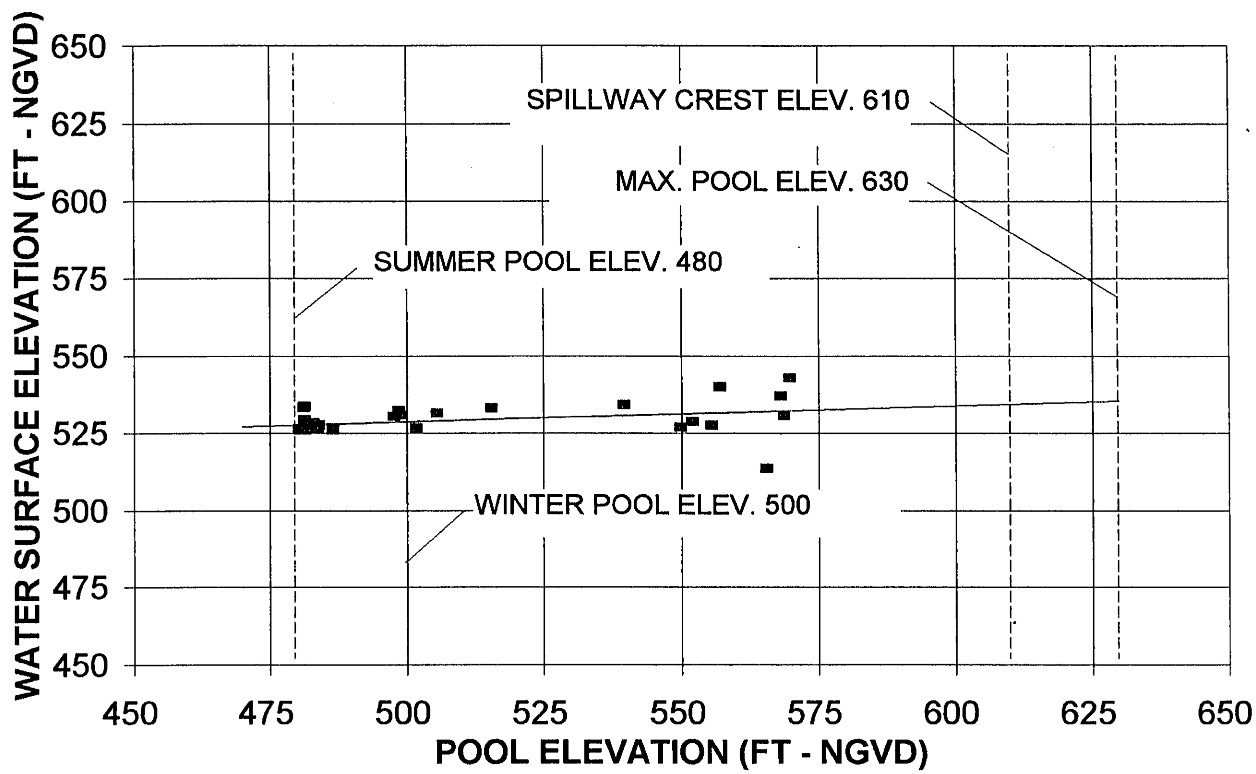
SCALE: AS SHOWN

JULY 1995

FIGURE 32

FILE NO. 11163-006

PZ-12B



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-12B

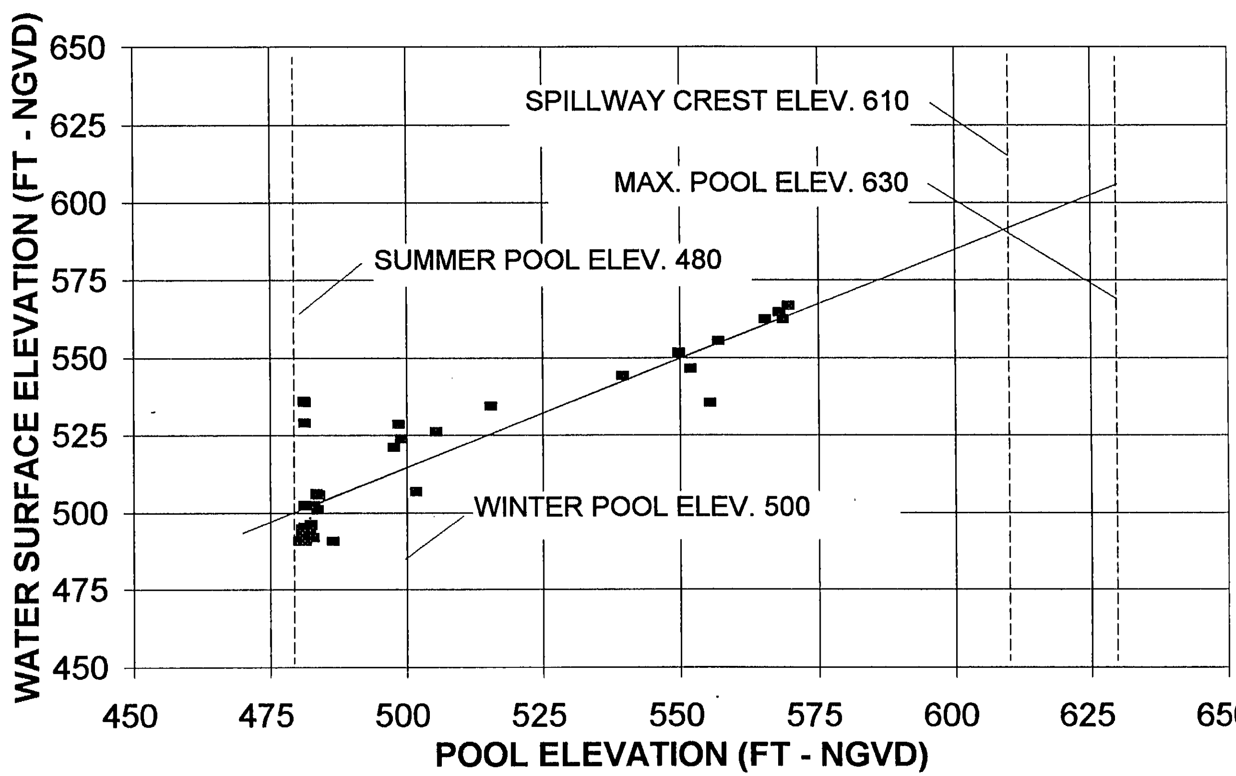
SCALE: AS SHOWN

JULY 1995

FIGURE 33

FILE NO. 11163-006

PZ-13A



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-13A

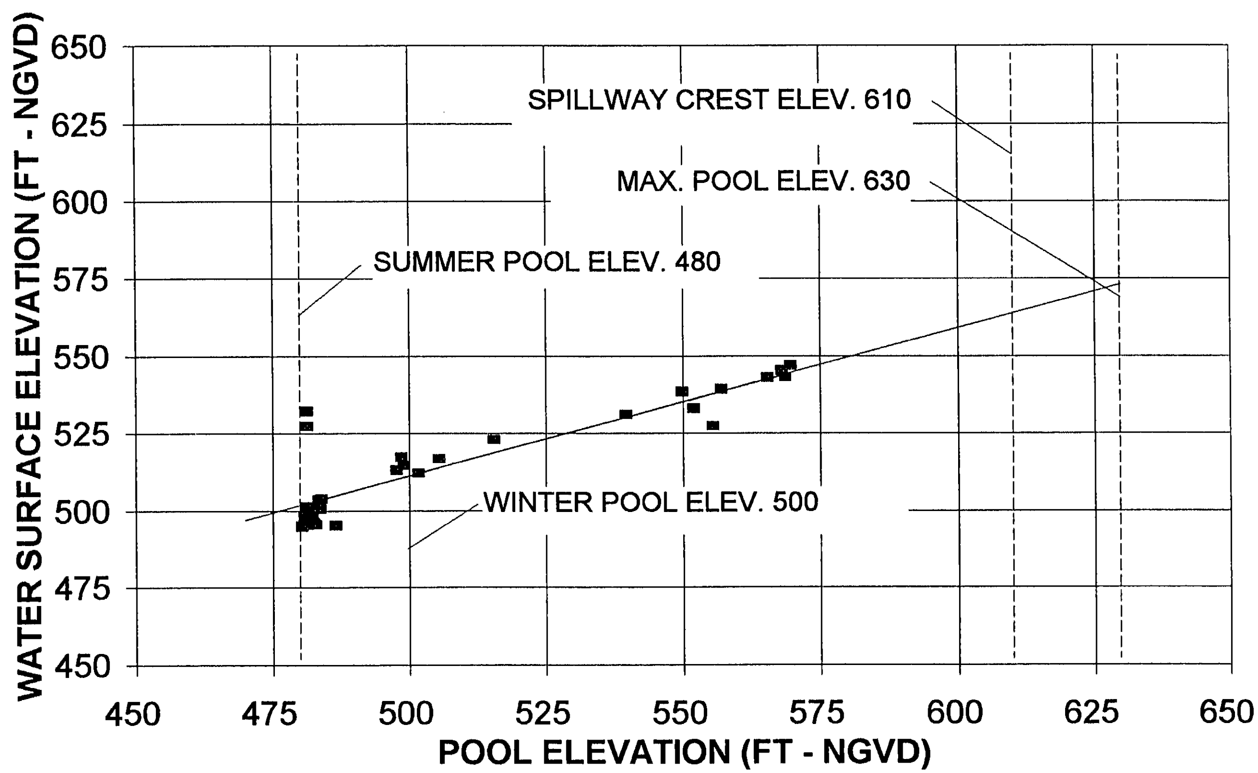
SCALE: AS SHOWN

JULY 1995

FIGURE 34

FILE NO. 11163-006

PZ-13B



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

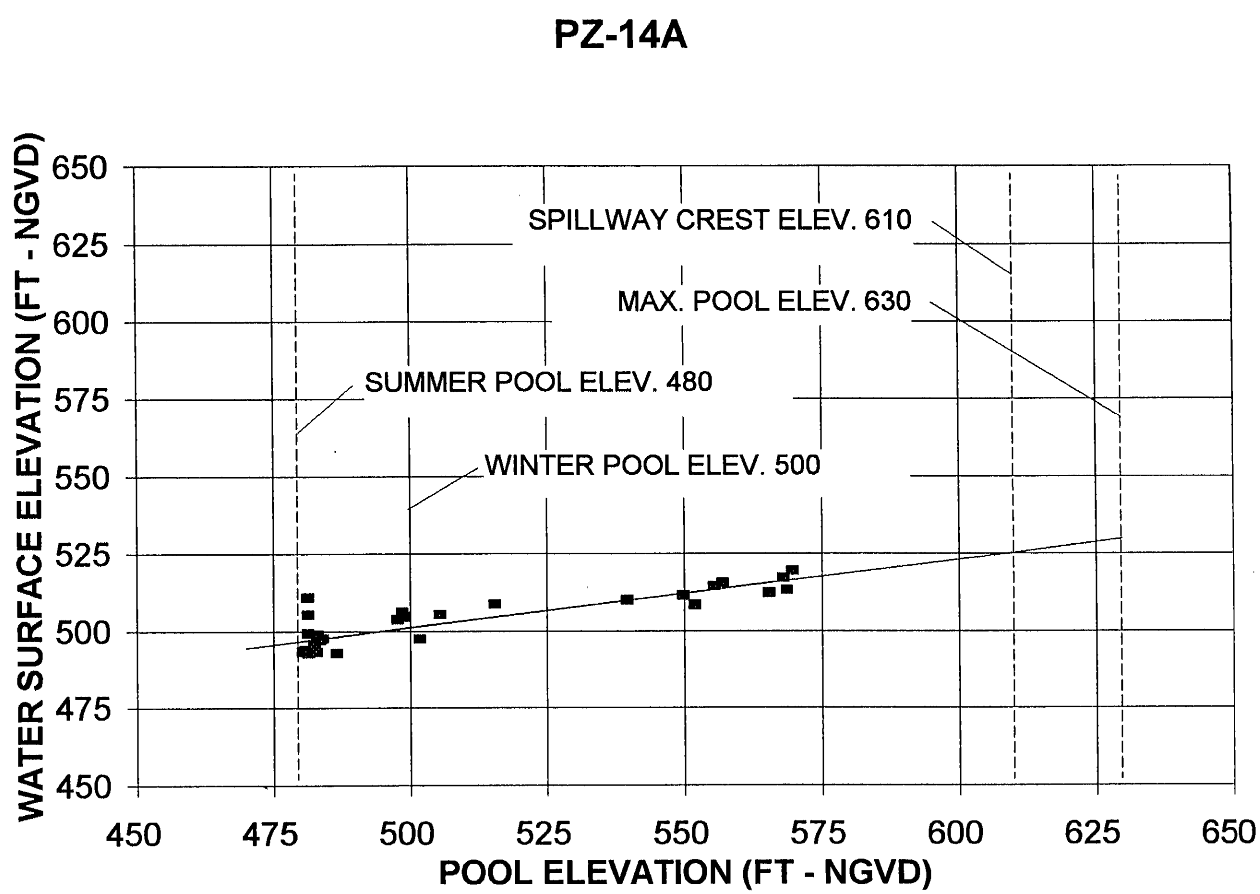
PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-13B

SCALE: AS SHOWN

JULY 1995

FIGURE 35

FILE NO. 11163-006



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

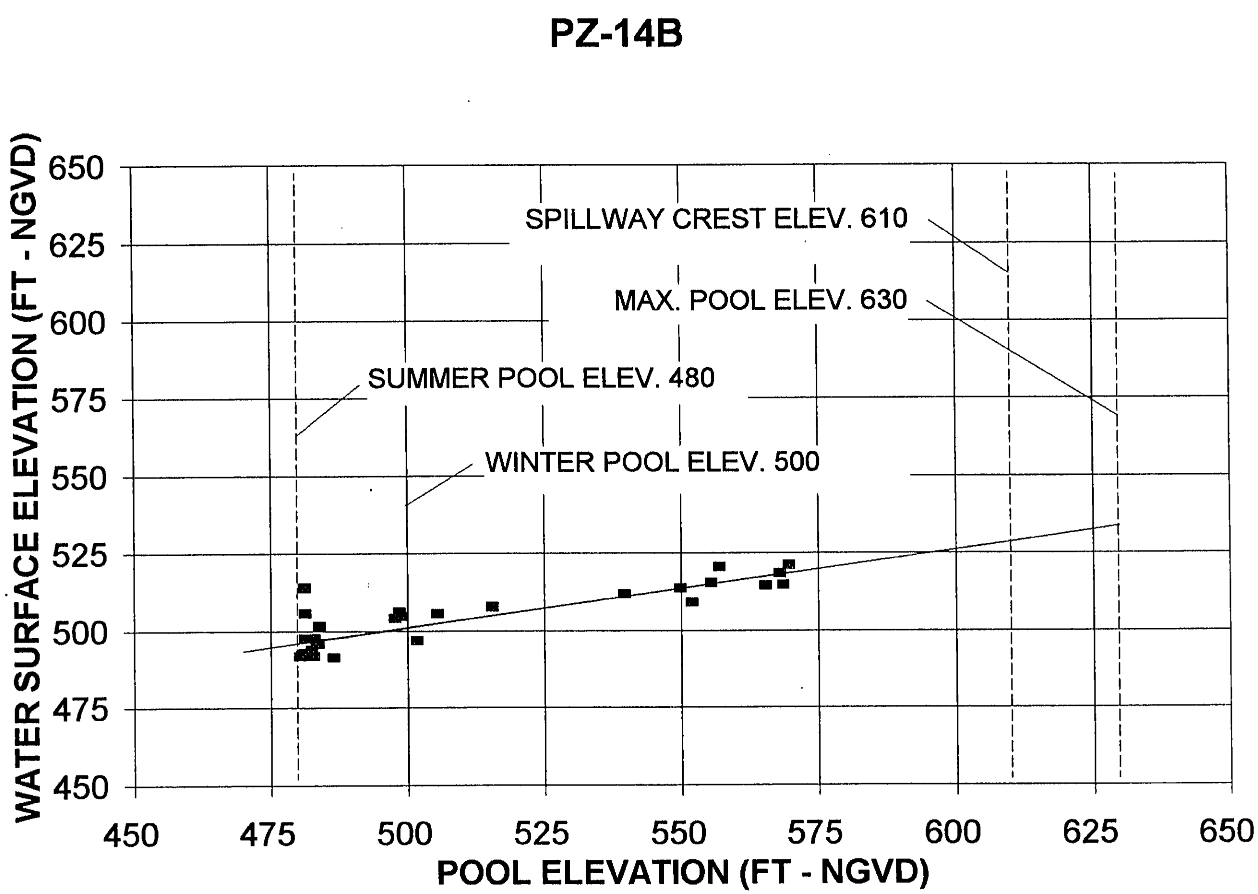
PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-14A

SCALE: AS SHOWN

JULY 1995

FIGURE 36

FILE NO. 11163-006



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-14B

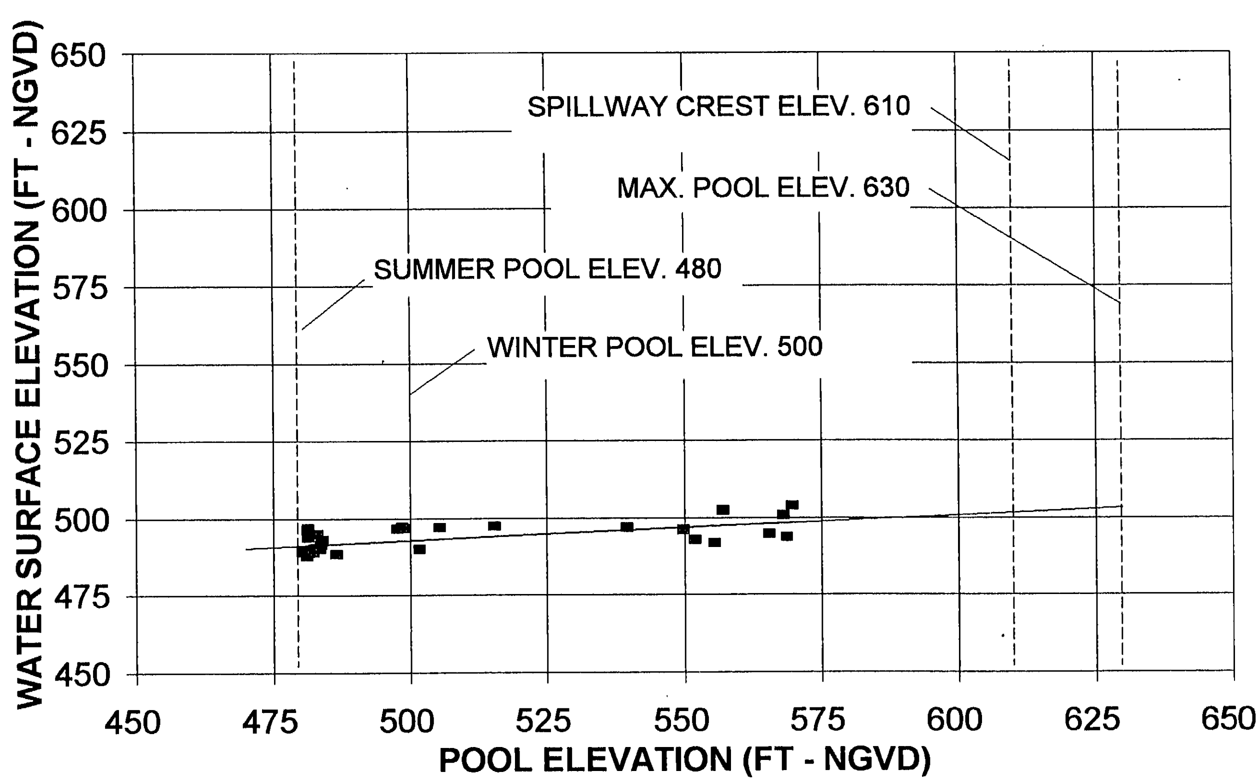
SCALE: AS SHOWN

JULY 1995

FIGURE 37

FILE NO. 11163-006

PZ-15A



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION
vs. POOL ELEVATION
PZ-15A

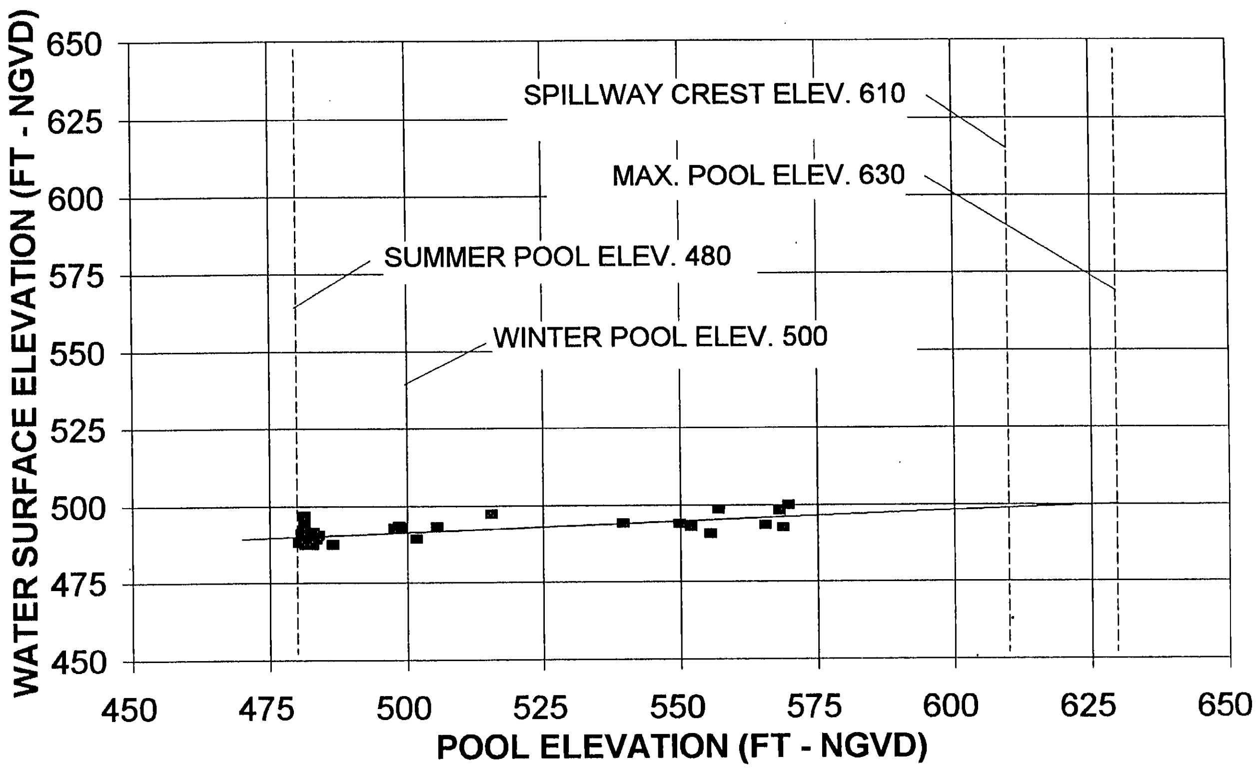
SCALE: AS SHOWN

JULY 1995

FIGURE 38

FILE NO. 11163-006

PZ-15B



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-15B

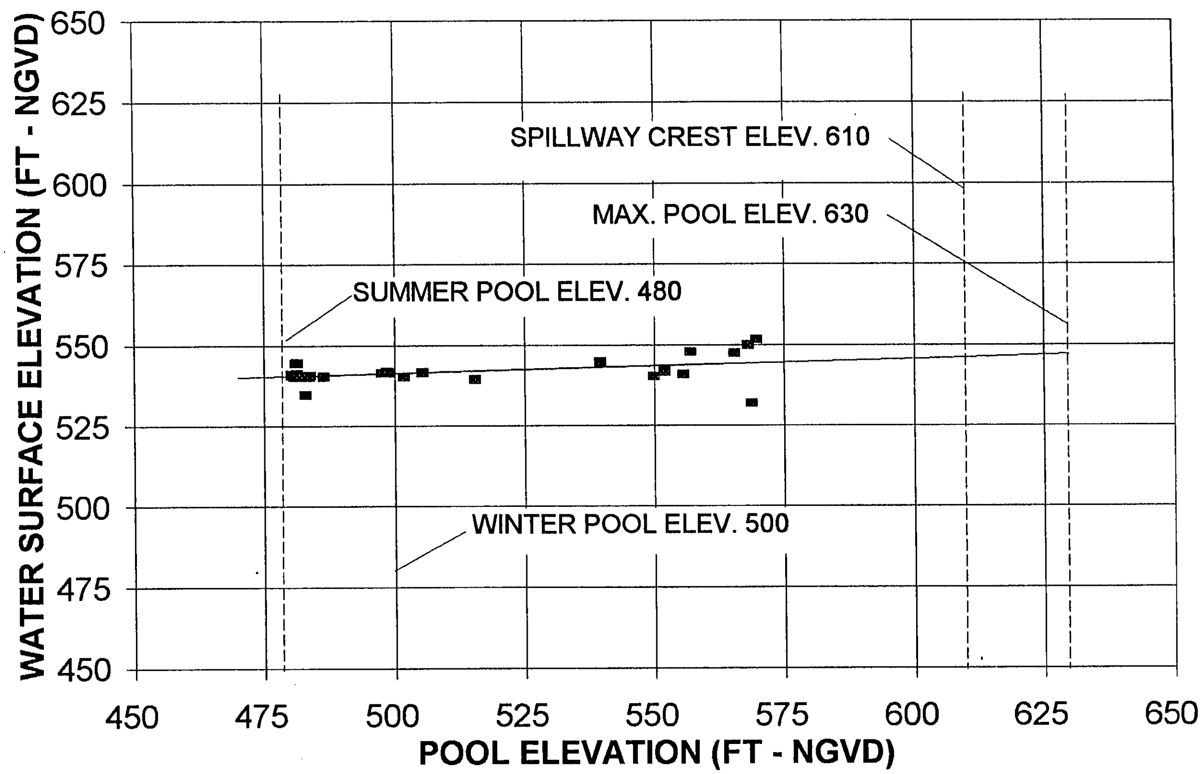
SCALE: AS SHOWN

JULY 1995

FIGURE 39

FILE NO. 11163-006

PZ-16A



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

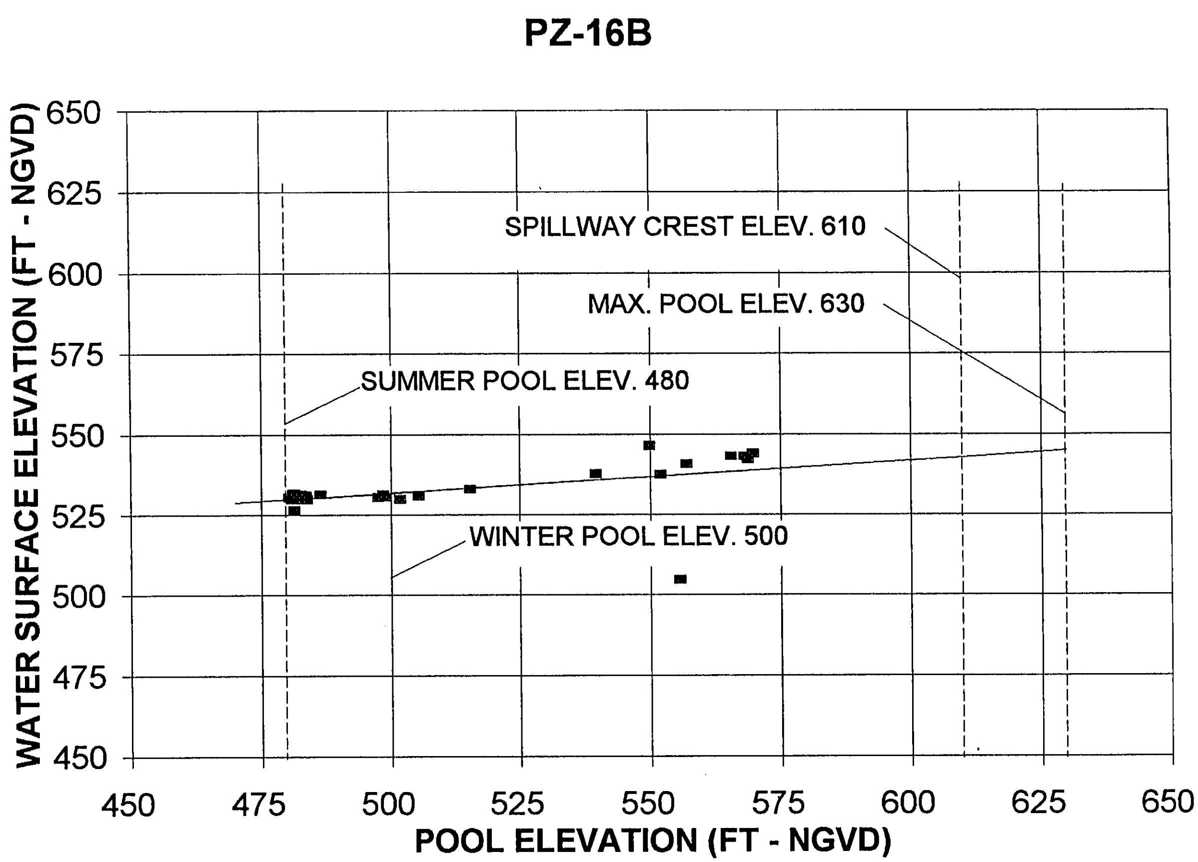
PIEZOMETER ELEVATION
vs. POOL ELEVATION
PZ-16A

SCALE: AS SHOWN

JULY 1995

FIGURE 40

FILE NO. 11163-006



HALEY & ALDRICH INC.

Geotechnical Engineers & Environmental Consultants

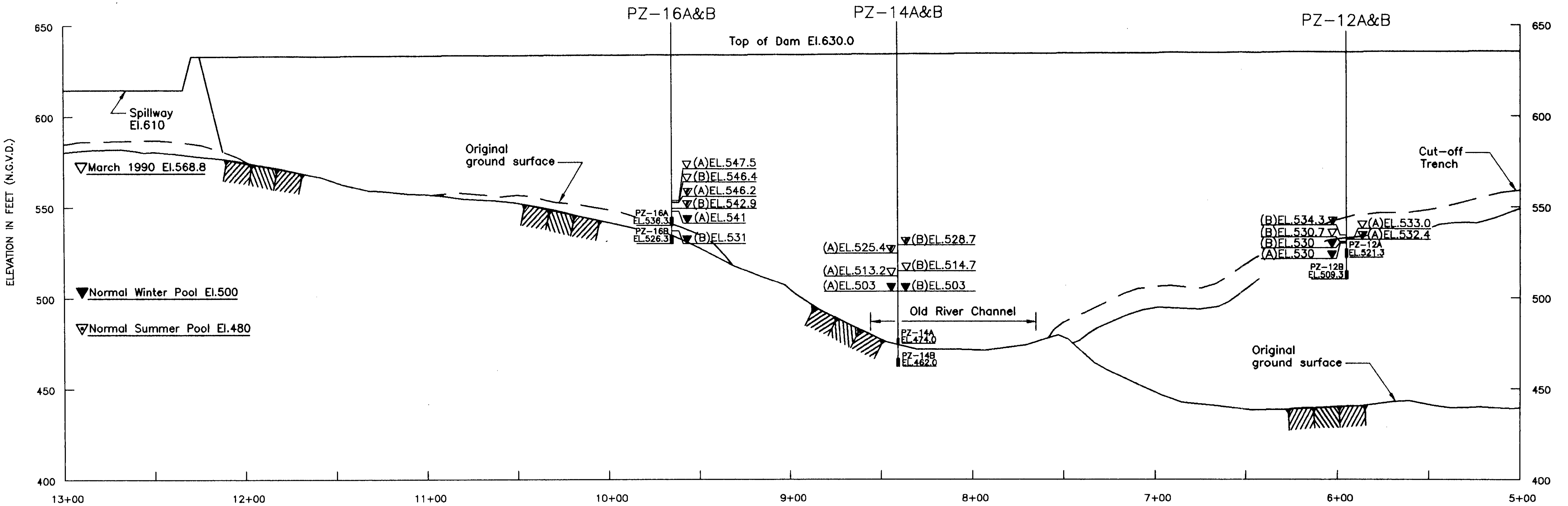
CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER ELEVATION vs. POOL ELEVATION PZ-16B

SCALE: AS SHOWN

JULY 1995

FIGURE 41



PROFILE ALONG CENTERLINE OF DAM (LOOKING UPSTREAM)

LEGEND:

- ▼ PIEZOMETER LEVEL AT WINTER NORMAL RIVER LEVEL
- ▽ PROJECTED PIEZOMETER LEVEL WITH POOL AT SPILLWAY CREST
- ▽ MARCH 1990 EVENT

NOTES:

1. CROSS SECTIONS PREPARED BY THE U.S. ARMY CORPS OF ENGINEERS AND PUBLISHED IN THE REPORT ENTITLED "PERIODIC INSPECTION REPORT NO.1, KNIGHVILLE DAM, CONNECTICUT RIVER BASIN, WESTFIELD RIVER, MASSACHUSETTS.
2. ALL ELEVATIONS CORRESPOND TO FEET N.G.V.D.
3. REFER TO FIGURE 6 FOR GENERAL LEGEND AND NOTES.
4. REFER TO FIGURE 7 FOR DESCRIPTION OF ENGINEERING LOGS.

0 60 120
SCALE IN FEET

HALEY & ALDRICH, INC.

Geotechnical Engineers & Environmental Consultants

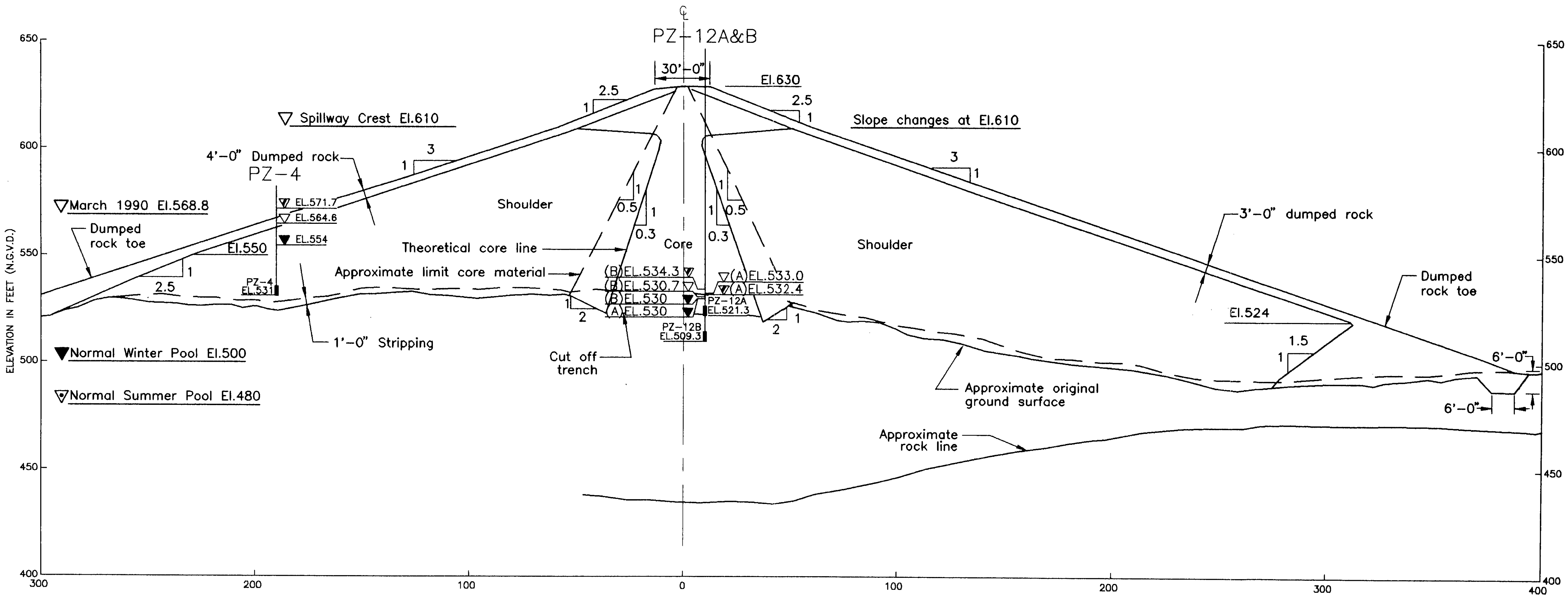
CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER LEVELS, NORMAL POOL AND PROJECTED TO SPILLWAY CENTERLINE OF DAM

SCALE: AS SHOWN JULY 1995

11163-006 B66

FIGURE 42



SECTION – STA. 6+00

NOTES:

1. CROSS SECTIONS PREPARED BY THE U.S. ARMY CORPS OF ENGINEERS AND PUBLISHED IN THE REPORT ENTITLED "PERIODIC INSPECTION REPORT NO. 1, KNIGHTVILLE DAM, WESTFIELD RIVER BASIN, HUNTINGTON, MASSACHUSETTS."
2. ALL ELEVATIONS CORRESPOND TO FEET N.G.V.D.
3. REFER TO FIGURE 6 FOR GENERAL LEGEND AND NOTES.
4. REFER TO FIGURE 7 FOR FULL DESCRIPTION OF ENGINEERING LOGS.

LEGEND:

- ▼ PIEZOMETER LEVEL AT WINTER NORMAL RIVER LEVEL
- PROJECTED PIEZOMETER LEVEL WITH POOL AT SPILLWAY CREST
- ▽ MARCH 1990 EVENT

0 50 100
SCALE IN FEET

HALEY & ALDRICH INC
Geotechnical Engineers & Environmental Consultants

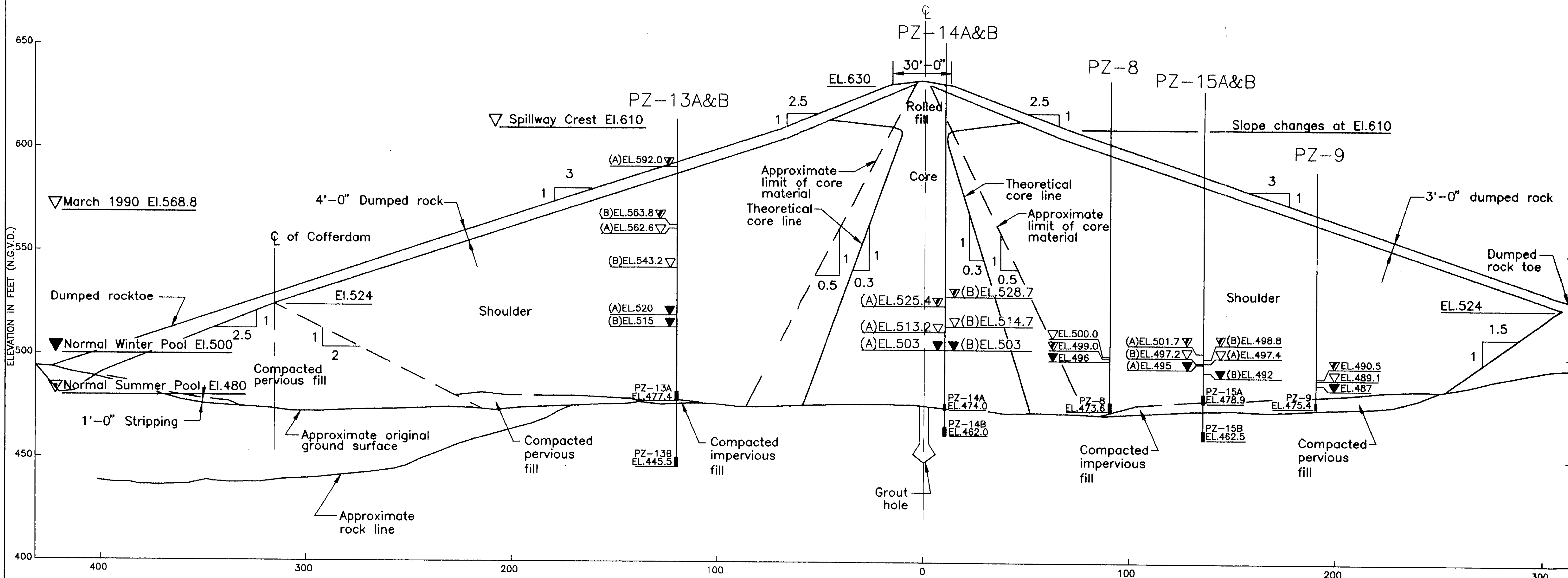
CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER LEVEL, NORMAL POOL AND PROJECTED TO SPILLWAY STA. 6+00

SCALE: 1"–50'
JULY 1995

11163-006 B58

FIGURE 43



SECTION - STA. 8+75

NOTES:

1. CROSS SECTIONS PREPARED BY THE U.S. ARMY CORPS OF ENGINEERS AND PUBLISHED IN THE REPORT ENTITLED "PERIODIC INSPECTION REPORT NO. 1, KNIGHTVILLE DAM, WESTFIELD RIVER BASIN, HUNTINGTON, MASSACHUSETTS."
2. ALL ELEVATIONS CORRESPOND TO FEET N.G.V.D.
3. REFER TO FIGURE 6 FOR GENERAL LEGEND AND NOTES.
4. REFER TO FIGURE 7 FOR FULL DESCRIPTION OF ENGINEERING LOGS.

LEGEND:

▼ PIEZOMETER LEVEL AT WINTER NORMAL RIVER LEVEL

▽ PROJECTED PIEZOMETER LEVEL WITH POOL AT SPILLWAY CREST

▽ MARCH 1990 EVENT

0 50 100
SCALE IN FEET

HALEY & ALDRICH INC.
Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

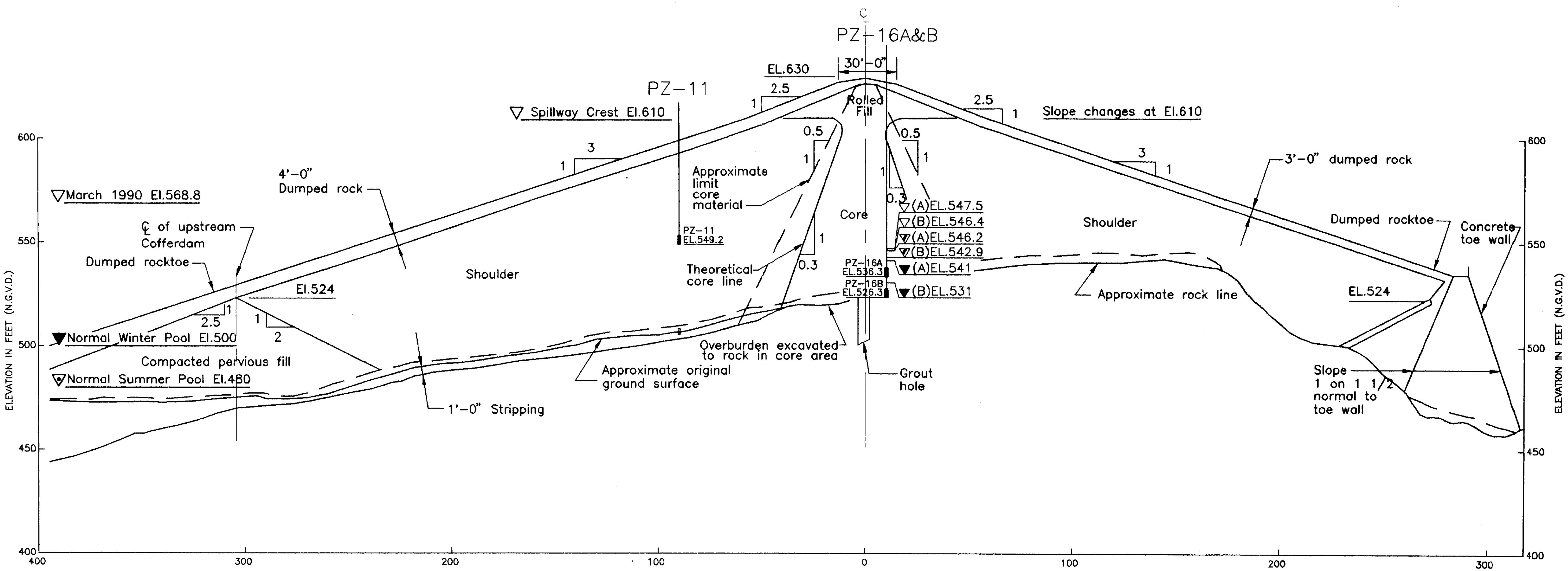
PIEZOMETER LEVEL, NORMAL POOL AND PROJECTED TO SPILLWAY FOR STA. 8+75

SCALE: 1"=50'

JULY 1995

11163-006 B59

FIGURE 44



SECTION – STA. 10+50

NOTES:

1. CROSS SECTIONS PREPARED BY THE U.S. ARMY CORPS OF ENGINEERS AND PUBLISHED IN THE REPORT ENTITLED "PERIODIC INSPECTION REPORT NO. 1, KNIGHTVILLE DAM, WESTFIELD RIVER BASIN, HUNTINGTON, MASSACHUSETTS."
2. ALL ELEVATIONS CORRESPOND TO FEET N.G.V.D.
3. REFER TO FIGURE 6 FOR GENERAL LEGEND AND NOTES.
4. REFER TO FIGURE 7 FOR FULL DESCRIPTION OF ENGINEERING LOGS.
5. PZ-11 WAS DRY DURING NORMAL WINTER POOL LEVELS AND THE MARCH 1990 EVENT. THEREFORE, NO WATER LEVELS ARE SHOWN.

LEGEND:

▼ PIEZOMETER LEVEL AT WINTER NORMAL RIVER LEVEL

▽ PROJECTED PIEZOMETER LEVEL WITH POOL AT SPILLWAY CREST

▽ MARCH 1990 EVENT

0 50 100
SCALE IN FEET

HALEY & ALDRICH, INC.
Geotechnical Engineers & Environmental Consultants

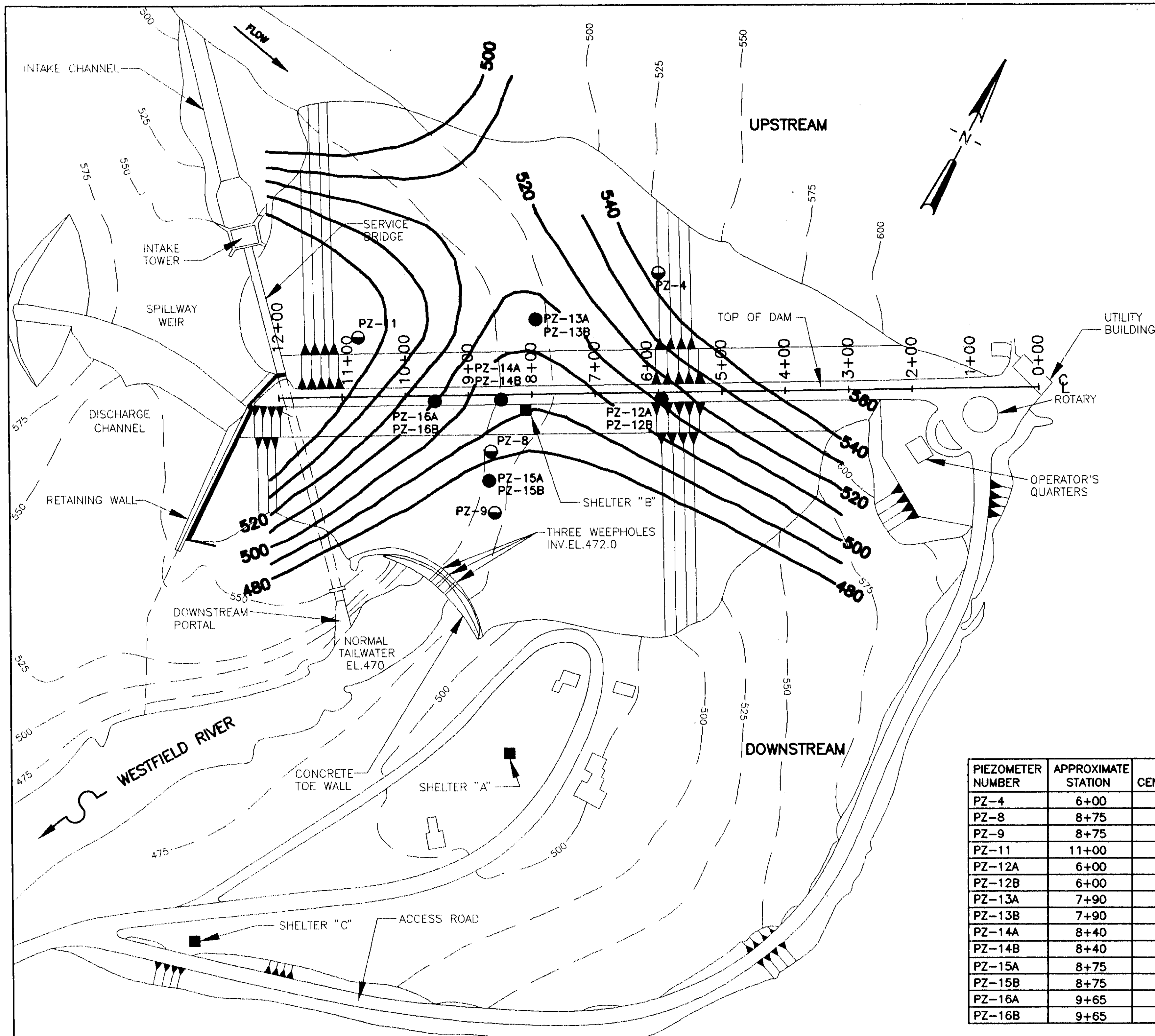
CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PIEZOMETER LEVEL, NORMAL POOL AND PROJECTED TO SPILLWAY FOR STA. 10+50

SCALE: 1"=50'   JULY 1995

11163-004 B57

FIGURE 45



LEGEND:

PZ-3 PIEZOMETER/SETTLEMENT GAGE INSTALLED DURING CONSTRUCTION

PZ-12A PZ-12B PIEZOMETER INSTALLED IN 1989

525 CONTOUR (APPROX. EXISTING SLOPE ELEVATION GROUND SURFACE)

OLD RIVER CHANNEL

NOTES:

1. PLAN PREPARED BY THE U.S. ARMY CORPS OF ENGINEERS.
2. ALL ELEVATIONS CORRESPOND TO N.G.V.D.
3. REFER FIGURE 6 FOR GENERAL LEGEND AND NOTES.
4. CONTOURS GENERATED USING SURFER, VERSION 4.15 SOFTWARE DEVELOPED BY GOLDEN SOFTWARE, INC., 1990.
5. WATER LEVELS FROM PZ-11, 12A, 13A, 14B, 15 B AND 16B NOT USED TO GENERATE CONTOURS.

PIEZOMETER NUMBER	APPROXIMATE STATION	APPROXIMATE CENTERLINE OFFSET	RISER PIPE TOP ELEVATION	PIEZOMETER TIP ELEVATION	ZONE LOCATED	MATERIAL AT TIP ELEVATION (3)
PZ-4	6+00	190 U/S	569.3	531.0 (2)	FOUNDATION	N/A
PZ-8	8+75	90 U/S	604.7	473.6 (2)	FOUNDATION	N/A
PZ-9	8+75	190 D/S	568.8	475.4 (3)	FOUNDATION	N/A
PZ-11	11+00	90 U/S	603.2	549.2 (2)	SHOULDER FILL	N/A
PZ-12A	6+00	10 D/S	630.3	521.3	IMPERVIOUS CORE	Medium br. SILT w/sand (22)
PZ-12B	6+00	10 D/S	630.3	509.3	FOUNDATION	Medium br. silty (30-40) SAND w/gravel (5-15)
PZ-13A	7+90	120 U/S	598.5	477.4	SHOULDER FILL	Lt. br. silty (15-25) SAND w/gravel
PZ-13B	7+90	120 U/S	598.5	445.5	FOUNDATION	Bedrock
PZ-14A	8+40	10 D/S	629.9	474.0	FOUNDATION	Medium br. silty (12) SAND and GRAVEL
PZ-14B	8+40	10 D/S	629.9	462.0	FOUNDATION	Bedrock
PZ-15A	8+75	135 D/S	589.8	478.9	SHOULDER FILL	Medium br. silty (5-15) SAND
PZ-15B	8+75	135 D/S	589.8	462.5	FOUNDATION	Bedrock
PZ-16A	9+65	10 D/S	630.3	536.3	IMPERVIOUS CORE	Dk. br. SILT w/sand (20)
PZ-16B	9+65	10 D/S	630.3	526.3	FOUNDATION	Bedrock

0 200 400
SCALE IN FEET

HALEY & ALDRICH INC
Geotechnical Engineers & Environmental Consultants

CONNECTICUT RIVER BASIN FLOOD CONTROL
WESTFIELD RIVER
KNIGHTVILLE DAM
HUNTINGTON, MASSACHUSETTS

PHREATIC SURFACE PLAN AVERAGE WINTER POOL ELEVATION

SCALE: 1" = 200' JULY 1995

11163-006 B60

FIGURE 46

APPENDIX A

Standards for Settlement Survey

APPENDIX A

STANDARDS FOR SETTLEMENT SURVEYS

1. Control points are stamped brass disks preferably set in a ledge area. Where no ledge is available, they are set in concrete bounds placed flush with the ground.

2. Control points are set in areas such that the maximum possible number of crest monuments on the dam are visible.

3. Control points are tied into four reference points by distance. This provides a check each time they are occupied for settlement surveys or allow them to be replaced if found to be destroyed.

4. Distances are read and recorded between settlement bounds. Both distance and angle are read and recorded from the control points that are being occupied to locate each settlement bound on the dam.

5. In locating each settlement bound, a control point will be occupied setting 0-00'-00" (referenced line of site) on a second control point, reading and recording both interior and exterior angle closure, along with distances through each settlement bound located on the dam. Each settlement bound is located from a minimum of two control points. These locations are third order, class II survey with relative accuracies of not less than 1 part in 5,000.

6. Levels are run from control points through each settlement bound on the dam with a return run back into the control points to check the elevation closure on the run. Closure tolerance should be no greater than 0.05 feet. These levels are third order, class I survey with relative accuracies no less than 1 part in 10,000.

7. Crest monument surveys are performed using Topcon EDM Total Stations and recording both horizontal angles and horizontal distances.

PROCEDURE FOLLOWED FOR SETTLEMENT SURVEYS

The horizontal and vertical monitoring plan for settlement bound movement points employed a combination of triangulation and trilateration angle and distance techniques to survey the control network. Control points, in the form of stamped brass disks, were placed off the dam structure in areas from which the entire length of the dam is visible. Settlement bounds themselves, with stamped brass disks, were placed on the control points. Horizontal coordinates of the control points are based on the State Plane Coordinate System. Elevations of the control points are based on the National Geodetic Vertical Datum (NGVD). Control points are occupied utilizing an EDM Total Station; observed distances and angles (interior and exterior angles), between control points and settlement bound establishing permanent bench marks. Standard leveling techniques are followed. Levels are double run and the means of the front and back runs were computed and recorded.

DATA ADJUSTMENT

A combination of triangulation and trilateration surveying techniques are applied. Each crest monument is located from two control points whereby two sets of coordinates are calculated using adjusted field angles and compliments and EDM distances. The two sets of coordinates are averaged to give a net result. The averaged coordinates are then established on each settlement bound for use in determining shifts in the dam surface structure over a period of years by comparing repetitive surveys.